DUST EXPLOSIONS

CAUSES AND METHODS
OF PREVENTION

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DUST EXPLOSIONS.

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Dust Explosions

Theory and Nature of, Phenomena, Causes and Methods of Prevention

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To those who have given their lives, their time, and their attention and effort to the prevention of dust explosions that the lives of others may be more adequately protected, this book is dedicated.

PREFACE.

The subject of Dust Explosions has not received serious consideration until recent years. In fact no one seemed to have any conception that dust alone could explode. But the fact that a large number of explosions have been occurring in mines and industrial plants where no explosive gases were present has proved this idea to be false and has led to a study of this particular hazard. The loss of life and property which many of these explosions have entailed has increased the demand for a comprehensive and authoritative publication on the subject. In attempting to meet this demand the authors desire to give the facts as they have been found by investigation, in such a way that they may be easily understood and applied.

Following a series of disastrous explosions in coal mines in the United States in 1907, the Technological Branch of the U. S. Geological Survey started an investigation to determine the causes of these disasters and to develop means of prevention. An experiment station was established at Pittsburgh, Pa. In 1910 this division became a separate bureau, the U. S. Bureau of Mines, under the Department of the Interior. In connection with its study of mine explosions this Bureau has been interested in explosions in industrial plants since any information on the subject would help in solving the related problems. Consequently, when a disastrous explosion occurred in a feed-grinding plant in Buffalo, N. Y., in June, 1913, the Bureau of Mines made a careful study of it. In the course of the investigation the grain and milling men of that vicinity took a lively interest in the question, desiring to give and obtain all possible assistance so that similar disasters might be prevented. This led to a co-operation between the Bureau of Mines and the milling and grain interests of the country for the purpose of studying the causes of dust explosions in mills and elevators and developing means of prevention. This investigation was carried on at the Bureau of Mines for one year, being financed by the grain trade. In the fall of 1914 provision was made for continuation of the work on a permanent basis

by the Bureau of Chemistry of the U. S. Department of Agriculture, where it is being conducted at the present time.

To give an idea of the scope of the study of dust explosions and of the industries subject to such disasters, it may be stated that explosions are known to have occurred in flour mills, feed mills, grain elevators, starch, dextrine, and all grain-handling plants, sugar, candy, chocolate, malt, spice, linseed meal, cottonseed meal, paper, cork and linoleum, wood working, and sulphur factories, and in coal mines. In fact, all industrial plants in which a dust is produced in the handling of carbonaceous material, or the manufacture of various products from this material, are subject to the possibility of an explosion. Some idea of the extent of the industries affected and of the amount of property involved may be obtained from the census reports for 1919. These show that more than 21,000 establishments are manufacturing or creating dusts of an explosive nature, and that the valuation of the product is more than $6,700,000,000.

In approaching this subject it has seemed well to consider what a dust explosion really is and the different factors which affect its nature or behavior, what explosions have done and what has been learned in studying those which have occurred in the various industries, and then to discuss the measures which have proved most effective in preventing an explosion or in retarding its development when once started. It is the sincere desire of the authors, in bringing this matter to the attention of the public in this way, that many explosions may be prevented, and that thereby many lives and much property may be saved.

ACKNOWLEDGMENT.

The authors desire to acknowledge the obligations incurred in the preparation of this book and to express their appreciation of the valuable assistance given in the investigations which have made this publication possible. Thanks are due the various members of the Grain Dust Explosion Prevention Staff of the Bureau of Chemistry, U. S. Department of Agriculture, for assistance in compiling and arranging the data, charts and tables included in the text. Miss Marian E. Lapp of the Editorial Office, Bureau of Chemistry, gave valuable criticism on the literary arrangement of the manuscript. There are others, some unknown to the authors, who have assisted in obtaining the reports of explosions in foreign countries or contributed indirectly to the general fund of knowledge on the subject, and to these the indebtedness of the authors is also gratefully acknowledged.

CONTENTS.

LIST OF ILLUSTRATIONS.

LIST OF FIGURES AND PLATES.

FIGURES.

PLATES.

LIST OF TABLES.

CHAPTER I.

NATURE AND THEORY OF DUST EXPLOSIONS.

A clearer idea of the nature of dust explosions will be obtained if they are considered in comparison with another type of explosion. In these days of internal combustion engines all are more or less familiar with the subject of gas explosions. Mixtures of different types of gases will explode under proper conditions, but the *best known* explosive mixture is one of an inflammable gas and air, such as gasoline gas and air, or methane (mine gas) and air. Before it is possible to have an explosion of any of these mixtures, two conditions must be present, namely, a proper mixture of the gases and a source of heat of sufficient intensity to ignite the mixture.

Dust Explosions and Gas Explosions Compared.

In a gas explosion there are at least two steps, the ignition and the propagation. When a source of ignition comes in contact with any part of an explosive gas mixture, the particles of gas in the immediate vicinity ignite. If there is a proper mixture of gases the heat given off by the burning of one or more of the gas particles will ignite the surrounding particles, and they, in turn, will ignite the particles of gas around them. In this way the ignition will proceed, continuing to propagate in concentric circles as far as the inflammable gas mixture is present. The rate of propagation is dependent upon the percentage of gas in the mixture and also upon its inflammability. Under certain conditions the flame will propagate with explosive violence, as, for example, through a mixture of methane and air if more than 5.5 per cent and less than 14 per cent of the gas is present. The most rapid propagation occurs in a mixture containing about 9.6 per cent of methane and 90.4 per cent of air. This is the most explosive mixture of methane and air, and when explosions occur in it there is not only the most rapid propagation of flame but the highest pressures are developed if the mixture is confined. As the lower or higher limits are approached the explosion becomes less violent, until a point is reached at the lower limit where the mixture is too lean (not enough gas present), or at the upper limit where the mixture is too rich (too much gas present), to have an explosion. Under the lower limit it may be considered that the inflammable gas particles

are not close enough together to allow the heat of combustion of one particle to ignite the particles nearest to it, and above the upper limit there is not a sufficient amount of oxygen present in the mixture to support the combustion of the gas.

If it is remembered that gases are made up of particles, but that these particles are so small that they cannot be seen, and that dust is simply a lot of separate particles large enough to be seen (though often not by direct light), and that when a cloud of dust is in suspension in the air it resembles a mixture of gas and air, in that the particles are surrounded by the air, it will be evident that gas mixtures and dust clouds are very similar. Therefore, it would be reasonable to expect that gas explosions and dust explosions would be similar and that the same laws would control them in almost every particular.

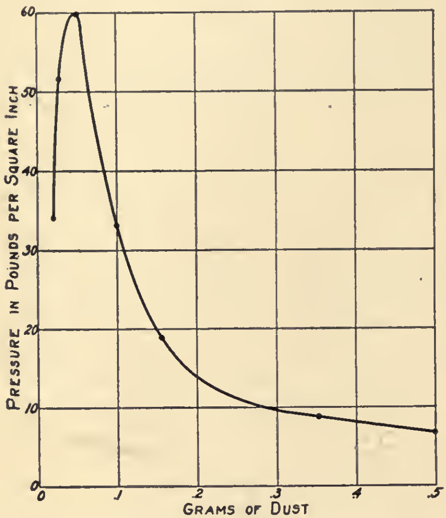

Fig. 1.
Relation of Amount of Dust to Inflammability.

In order to have a dust explosion every condition which has been given for gas explosions must exist. There must be a proper mixture of inflammable dust and air and there must be present a source of heat of sufficient intensity to ignite the dust. Ignition and propagation proceed in the same manner. There is also a lower and an upper limit to the amount of dust in suspension in the air, in which there can be an explosion, and a particular point at which the most violent explosion will take place for any particular dust. These facts may be deduced from a simple consideration of the relation between gas and dust particles. Fortunately, however, certain experimental data have been obtained which substantiate these statements, even though the investigations of dust explosions have not been as complete or as conclusive as those of gas explosions. This is probably due to the great difficulties encountered in maintaining or even obtaining a uniform dust cloud of any desired density.

However, some of these difficulties have been overcome by Dr. J. D. Morgan,[1] of England, in investigations which demonstrate that there are explosive limits for dust and air mixtures as for gas and air mixtures.

[1] Proc. of the Institution of Civil Engineers, vol. 196. Session 1913-1914. Part II. An apparatus of 105 cc. capacity was used.

Some of his results with lycopodium dust are shown in Figure 1. A curve for gases,[1] Figure 2, gives an opportunity for comparing the effects of varying percentages of dust or gas in the mixtures. It will be noticed that a certain amount of either must be present before an explosion can be obtained, that as the quantity is increased up to a certain point the mixtures become more explosive, and that increasing the amount of either beyond that point causes a decrease in the explosive qualities. In discussing the curve in Figure 1, Dr. Morgan states: "It has been asserted that excess of dust cannot have a diminishing effect upon the maximum pressures obtainable from the explosion of a given dust, on the assumption that part of the dust in the cloud completely combines with the available air, and the remainder of the dust is unaffected. But, as the curve shows, excess of dust has a damping effect upon an explosion, and in every variety of experiment of which the author has any knowledge this fact was always observed."

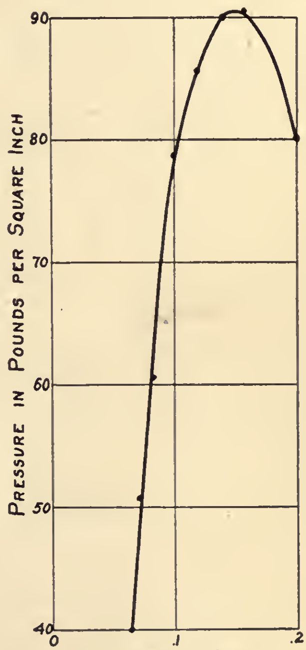

Fig. 2.
Relation of Amount of Gas to Inflammability.

It is not possible to judge by simply looking at a gas mixture whether it is explosive or not. But with a mixture of dust and air it is possible, after considerable experience, to judge by appearance whether a flame would propagate through it or not, knowing of course the sort of dust in the cloud. A man once said that, in his opinion, a dangerous condition would exist if he could see a haze caused by dust between himself and a 100-watt electric lamp about 15 feet away. If this were true, there would be many more explosions than at the present time, for this condition is frequently found in many if not in all mills where a fine powdery product is manufactured. As a matter of fact, it takes a fairly dense cloud of dust, as dust clouds are usually considered, to propagate a flame. It is possible to obtain some idea of this density by taking a small quantity of dust, putting it in a cheese cloth, or other thin or loosely woven fabric and shaking it out as a cloud over an open flame until the cloud coming in contact with the flame is dense enough to ignite and propagate. When judged by the eye this dust cloud may appear quite dense, but the actual weight of dust in any given space may be very small. For instance, it has been determined by the United States Bureau of

[1] Prepared by Dr. Morgan from table in The Gas Engine, 6th ed., p. 100, by Dr. Dugald Clerk.

Mines[1] that an explosion will propagate through a cloud of coal dust having only 0.032 ounce of dust per cubic foot of air space (32 grams per cubic meter), while in France a propagation was obtained with only 0.023 ounce per cubic foot and in Germany the lowest figure given is 0.040 ounce per cubic foot. While the amount of coal dust necessary for the most explosive mixture and the maximum amount of this dust which can be present and still have an explosion, have not been definitely established, it can be assumed from the gas analogy that the most explosive mixture would be the one in which there is just enough dust to utilize all the oxygen in the given volume. For the coal dust used by the Bureau of Mines this was found to be 0.123 ounce per cubic foot. So the minimum amount of coal dust necessary for an explosion may be considered to be about 0.023 ounce per cubic foot, while the most explosive mixture would contain about 0.123 ounce per cubic foot.

While no determinations as accurate as these have been made to establish the minimum amount of dusts other than coal dust necessary to propagate an explosion, it has been possible to obtain propagation of flame with as low as 0.030 ounce per cubic foot, and the indications were that propagation could be obtained with much less dust per unit volume. The fact that many of the inflammable dusts can be ignited more easily and at lower temperatures than coal dust under the same conditions, and that in the explosion which follows they will produce higher pressures, would indicate that an ignition could be obtained with a smaller amount of certain other dusts per cubic foot of air space than with coal dust. The amount of these dusts necessary to give the most explosive mixture has not been determined but, as in the case of coal dust, it might be considered to be that amount which would just utilize all the oxygen in a given volume. With starch, for instance, this would be 0.220 ounce per cubic foot.

These figures are in such units that it may be difficult to interpret them on the basis of the amount of dust that might be present in a portion of a factory. Should 0.030 ounce per cubic foot be taken as a lower limit, which is sufficiently high, it would be found that a flame will easily propagate through a room containing 5333 cubic feet, or one approximately 20x25x10 feet, if there are only 10 pounds of dust in the room; or the maximum explosive effect might be obtained in this same room if it contained only 70 pounds of starch dust, for example, or only 40 pounds of coal dust. These figures are very small comparatively when the actual amounts often present in certain factories and in some places in most factories producing powdered or semi-powdered products are considered.

Even though there might be present in a factory that amount of dust which would form the most inflammable mixture and which, if ignited, would propagate the flame more rapidly than any other mixture of that particular dust and air, and would have in it the possibility of producing very high pressures, the maximum possible velocity and pressure

[1] U. S. Bureau of Mines Bull. 20, p. 48.

would probably never be reached. This would be entirely due to the fact that the walls of factories are not built to withstand anywhere near as high pressure as may be developed in such an explosion, or in fact in any explosion having more force than that created by a simple propagation. This will be brought out more fully in a later chapter, but a statement here of some of the pressures and velocities obtained in certain gas and dust explosions made within containers especially constructed, will illustrate this point and also give a clearer idea of the relation between dust and gas explosions. Under different conditions and with different dusts, the Bureau of Mines and the British and French Experiment Stations have measured velocities of from 2,000 to 3,300 feet per second, while in certain tests there have been indications of velocities considerably higher than these, in fact of over 6,000 feet per second. Different experimenters have determined the maximum velocities of propagation of flame in gas mixtures and have given the following results:

	Velocity per second. Meters.	Feet.
2 parts hydrogen + 1 part oxygen	2820	9250
4 parts coal gas + 5 parts oxygen	2700	8876
1 part ethylene + 3 parts oxygen	2364	7724
1 part methane + 2 parts oxygen	2322	7616
2 parts carbon monoxide + 1 part oxygen	1680	5510

In large-scale tests with coal dusts, pressures have been obtained as high as 270 pounds per square inch, while in one test at the French Experiment Station the steel gallery, with an estimated breaking strength of 570 pounds per sq. in., gave way, pieces of the sheet steel being thrown distances up to 150 meters (472 feet). No such accurate tests have been made with inflammable dusts other than coal dust. However, a few tests were made with flour and starch in a steel gallery erected by the Bureau of Mines. This gallery was 220 feet in length and 6 feet in diameter. Each 10-foot section had an 18-inch opening at the top covered with a heavy iron door which would open and relieve the pressure. Instruments were placed along the gallery to record the pressures and velocities obtained in the tests. The conditions were such that results could not be considered accurate. However, flour gave about the same pressures and velocities as did coal—which was used for comparison—while starch gave velocities fully twice as great as those given by coal and pressures 8 to 10 times greater. On account of the vents on the gallery, these were not exceptionally high, being only a little over 30 pounds pressure per square inch, and velocities of around 2,000 feet per second, but the results show that higher pressures and velocities may be obtained in explosions of dusts other than coal. As will be shown later in this chapter, the pressure in small explosion tests was sometimes fully 50 per cent higher with certain dusts than that produced with coal dust. Consequently it would be reasonable to expect that pressures of at least 300 to 400 pounds per square inch might be developed in explosions of these materials. With a mixture of 1 vol. methane + 2 vol. oxygen + 9 vol. air a pressure of 97.5

pounds per square inch was obtained, while with a mixture of 2 vol. hydrogen + 1 vol. oxygen a pressure of 310.5 pounds per square inch was obtained. In all these tests the mixtures of gases as well as those of dust and air were at atmospheric pressure when ignited.

It will be noted that as high pressures have been obtained in coal dust explosions as in gas explosions. However, the extremely high velocities attained by the flame in certain gas mixtures have not been reported as occurring in dust explosions. This could not be expected, for the finest dust particles are many times larger than gas molecules, and so, even in the densest dust clouds, the particles could not be as close together or as intimately mixed with the oxygen as are gas molecules. Therefore, the heat created by the burning of one dust particle cannot be as readily transmitted to the next particle as it can be in a mixture of gases.

It is generally agreed that after a dust explosion is well under way, or at least has reached the velocity of a detonating wave, that is, in excess of 2,000 feet per second, the only action which takes place is the rapid burning of the dust. In the propagation of an explosion a heat wave precedes the flame and explosion wave. It has been thought that in the early stages of an explosion this heat causes a distillation of gas from the dust, resulting in an explosion of the combination of gas and dust. As explosions of gases were studied much earlier than explosions of dusts, it was considered at first that there could be no such thing as an explosion of dust without the presence of a gas. In some of the earlier investigations it was not possible to obtain an ignition of dust alone, but ignitions were obtained when a small amount of gas was present, that is, less than the minimum amount necessary for a gas explosion. In more recent investigations the question has been raised as to just what does take place in the early stages of an explosion and particularly at the time of ignition of dusts.

French experimenters[1] devised an apparatus for testing the inflammability of dust and determining the amount of volatile matter given off in instantaneous heating. In the apparatus a cloud of dust was blown downward through a porcelain tube, externally heated, the temperature of the inside wall being regarded as a measure of the inflammability. With this apparatus a sample of coal dust was blown through the tube at 700° C., at which temperature it did not inflame. Before the test the content of volatile matter of the dust was 28.4 per cent. This percentage was lowered 2.2 per cent in the momentary heating to which the dust was subjected in passing through the apparatus. It was considered that this decrease demonstrated the evolution of volatile matter preceding inflammation.

British experimenters,[2] after a long series of tests, came to the con-

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[1] M. J. Taffanel and M. A. Durr, Inflammation de poussières. 5th ser., 1911, p. 34.

[2] Great Britain, Home Department, Second report of the explosions in mines committee, 1912, p. 43, and R. V. Wheeler, The volatile constituents of coal, part 4. The relative inflammability of coal dusts: Jour. Chem. Soc., vol. 103, 1913, pp. 1715-1734.

clusion that control of the dust with the source of ignition for too long a time permits appreciable if not complete distillation of some particles of dust, at least enough to form local mixtures of lower explosive limits from any high volatile coal. They show that in a very short period of contact volatile matter is given off from only the more easily decomposable constituents. However, the amount of gas which is given off in the normal period of contact does not seem to be sufficient to form an explosive mixture throughout the cloud, and the British authorities are of the opinion that the propagation of the explosion in the early stages takes place in the same way as in the later stages, simply by rapid burning of the dust.

For some time the United States Bureau of Mines[1] has been working on this problem, so far using two different methods of testing, one being to drop a heated body through a cloud of dust and the other to raise a cloud of dust with a blast of hot gases which were heated to temperatures sufficient to ignite the dust. In both methods, when the apparatus contained air, ignitions were easily obtained. Nitrogen was then used and the gases given off in the momentary heating were analyzed. Besides coal, tests were also made with wheat starch, stinking smut of wheat, cornstarch and dextrine.

As a result of these two entirely independent investigations, in which radically different methods of igniting the dust cloud were used, it is evident that it is at least possible to inflame coal dust suspensions in air under conditions wherein the predistillation of gas appears to be so slight that it can not be considered an effective factor in causing ignition. The alternative explanation seems to be a direct attack upon the finely divided dust by oxygen molecules. That the size of the dust particles is an important factor in the relative inflammability of dusts of the same character has long been appreciated. This fact lends weight to the direct-attack hypothesis.

Although in some of the many experiments tried, unmistakable but slight quantities of combustible gas, largely carbon monoxide, were found after momentary heating of dust by the methods used, no relation could be traced between its relative quantity and the known relative inflammability of the dusts.

On page 41 a table is given showing the gases evolved in the heating of coal, cellulose and starch. While this distillation is at temperatures considerably lower than the temperatures of inflammation or at least of propagation of explosions, the results bear out the conclusions of the Bureau of Mines and indicate that in the early stages of explosions the same process goes on as in the later stages, namely a direct burning, or as stated by the Bureau of Mines, "a direct attack upon the finely divided dust by oxygen molecules."

Although dust particles in suspension have such comparatively large exposed surfaces that there may be a very rapid distillation of gases when heat is applied, the fact that the volatile content of some dusts is largely of a non-flammable material, together with the facts brought out

[1] U. S. Bureau of Mines. Reports of Investigations, No. 2306, 1922.

above, seems to prove that in the ignition of the dust there is simply a rapid burning or oxidation of the particles themselves, instead of a distillation of gases and either a gas explosion or a combination gas and dust explosion.

Unless all the conditions which might possibly affect the inflammability of a dust are known it is difficult to state offhand what dusts are explosive, or whether a certain dust will explode or is dangerous. One broad principle which may be used as a guide in determining what dusts are explosive or dangerous is that any dust from highly carbonaceous material or from any material that will burn may explode under proper conditions and is therefore dangerous from the explosion standpoint. The fact that coal dust is explosive has been brought out very forcibly by the large losses of life often accompanying a mine explosion. As an explosion often spreads throughout an entire mine, the large number of men working in it have no chance of escape. If not killed by the explosion itself they are suffocated by the gases. In a factory or mill the loss of life is not so great proportionately as the force of the explosion often does not reach all parts of the plant and the men who are not killed by the initial explosion have a chance to get out. Many of the most disastrous dust explosions in industrial plants have occurred at times when the plant was not in full operation. The percentage of life loss has been very high, indicating that an explosion during the normal working period of the day would result in extensive loss of life if the full force of employees were present. The largest number of men ever killed in a mine explosion is 358, at the Monongah mines in West Virginia, on December 6th, 1907. The largest number of lives lost in an explosion in a factory is 43. In this latter explosion, which occurred in a starch factory in Cedar Rapids, Iowa, in May, 1919, 30 others were injured. Less than a hundred persons were in the plant, but the day shift of over six hundred had left the factory not over a half hour before the explosion occurred. In explosions in factories the number injured often exceeds the number killed, as, for instance, in an explosion in a mill in Liverpool, in 1911, where 39 were killed and 101 injured. So, while the loss of life is usually less in factories than in mine explosions employees of both are subject to this hazard.

That carbonaceous dusts are explosive is accepted as a theory by many men prominently identified with various industries, but they seem to feel that their particular plants are immune. It is not so long ago that some of the flour millers would say that they never heard of a dust explosion in a flour mill, while elevator men would say that they knew of the danger in flour mills, but most of them thought that elevator dusts contained too much field dirt to be explosive. However, since all carbonaceous dusts may explode, every possible precaution should be taken, not only in flour mills and elevators, but in every industry producing carbonaceous dusts, and, in fact, in other industries as well, for explosions of aluminum dusts have occurred, and there is one report of an explosion of iron dust. The authors have not been able to verify this report. In addition to those already referred to, explosions of the following dusts are known to have

occurred: All dusts from grains or cereals, such as flour and elevator dusts, starch, feed and malt dusts; and dusts from bark, cork, cotton seed meal, cotton lint and flyings, fertilizer, herbs, leather, paper, spices and coffee, sugar, wood and wool.

While it is true that these dusts are not equally dangerous, under the proper conditions all of them will explode. That there must be present a proper mixture of the dust and air and a source of heat of sufficient intensity to ignite the dust has been stated. The ease with which a dust ignites and propagates a flame is to a very large degree a measure of the hazard which may exist where that particular dust is present. This property is termed the "inflammability" of the dust. A measure of the relative inflammability of dusts, therefore, will give us some idea of their relative danger.

In the attempts which have been made to devise a satisfactory method of measuring this property of various dusts, most of the methods have been developed for testing coal dusts, but it has been possible to apply some of these in the testing of the relative inflammability of other dusts. In the earlier work little attempt was made to establish any relation between the different dusts, the chief object being to determine whether a dust was inflammable or not. Tests and observations on this subject have been made by Faraday,[1] Watson Smith,[2] Mallard and M. Le Chatelier,[3] Galloway,[4] Vital,[5] Bedson and Widdas,[6] Holtzwart and Meyer[7] and by men associated with experiment stations in England, France and the United States.

Vital was among the first to attempt to establish a relation between the various dusts, particularly coal dusts. He blew the dust as a cloud through a gas flame and into a long glass tube, at the far end of which was a light pith ball. The nature of the flame, the distance it traveled and the distance which the pith ball was moved by the force of the explosion gave an indication of the relative inflammability of the dust. Bedson and Widdas tested dusts by blowing them as a cloud into a glass globe in which was a coil of platinum wire that could be heated electrically. They found that different dusts required different temperatures, determined by the amount of current necessary to produce an ignition. Later they attached a water manometer to the apparatus and by keeping all conditions constant they found that with different dusts they obtained different pressures in the explosions. This gave them another method of measuring the explosive character of the dusts.

A method devised by Taffanel of the French Experiment Station consisted in blowing, by means of a blast of oxygen, a known quantity of dust over and against a definite sized flame of a benzene lamp, and

[1] Final Report, Accidents in Mines Comm., Eng. 1886, p. 30.
[2] J. Soc. Chem. Ind., vol. 25, 1906, p. 54.
[3] Annales des Mines, ser. 7, vol. 20, 1881, pp. 121-159.
[4] Proc. Roy. Soc. London, 1876, p. 168; Annales des mines, ser. 7, vol. 11, 1878, p. 229; Bull. Soc. Ind. Minerale, ser. 2, vol. 9, 1880, p. 157.
[5] Annales des mines, ser. 7, vol. 7, 1875, p. 180.
[6] Trans. Inst. Min. Eng., vol. 32, 1907, pp. 529-531.
[7] Dingler's Polytech J., vol. 280, 1891, pp. 185, 237.

then measuring, usually photographically, the length and size of the flame. In this way he was able to classify the various dusts in a certain order of their relative explosibility.

Following two serious explosions which occurred in England in 1911, Dr. R. V. Wheeler of the Explosions in Coal Mines Committee conducted a series of experiments on 66 different samples of dust collected from plants which would come under the jurisdiction of the Factory and Workshop Acts. He used two methods of testing, "one[1] for the purpose of

[1] Test No. 1—The Relative Ignition-Temperatures.—A glass cylinder, 8 cm. in diameter and 140 cm. long, open at both ends, is supported in a horizontal position (fig. 3). A platinum coil of 32 gauge wire, closely wound on a thin-walled tube of quartz of capillary bore, passes horizontally across the cylinder at a point 40 cm. from one end. Through the bore of the quartz tube a platinum and platinum-rhodium thermo-couple passes and is connected to a millivoltmeter

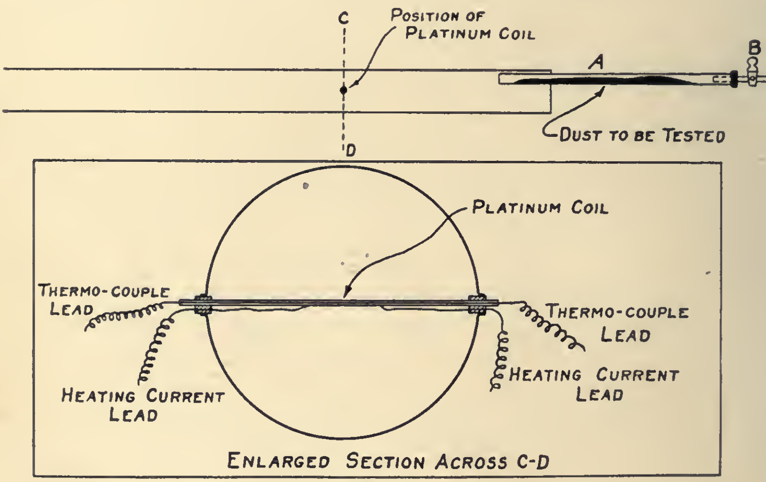

Fig. 3.

Relative Ignition Temperature Apparatus.

calibrated so as to read temperatures on the Centigrade scale. By means of suitable connections an electric current can be passed through the platinum coil so that it can be heated to any temperature up to about 1400° C., and maintained at a constant temperature by the adjustment of an external resistance. The length of the heated coil is 17 mm. and its diameter 1.5 mm.

The dust to be tested is placed in an even layer along a glass tube of 2.5 cm. internal diameter, 45 cm. long. This tube (A, fig. 3) is closed at one end by a rubber stopper carrying a glass tap (B) of 1 cm. bore. It is supported in the position shown in the diagram, the open end being at a distance of 30 cm. from the heated platinum coil. The tap is connected with an arrangement for giving a constant puff of air, consisting of a brass cylinder, 65 cm. long and of 11 cm. internal diameter, fitted with a piston weighted so as to give a pressure of 2 lbs. per square inch.

The platinum coil having been heated to such a temperature as preliminary trials may have indicated as being about that required, the dust cloud is produced by suddenly opening tap (B). The air-blast, passing over the surface of the dust in the tube (A), raises the top layer and carries it into the larger

discriminating between harmless and dangerous dusts, the other[2] with the intention of ascertaining the temperatures at which inflammation of the dangerous dusts takes place readily."

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tube and over the heated coil in a cloud that remains uniform during the stroke of the piston. If ignition occurs the temperature of the platinum coil is lowered 10° or 20° C. and a fresh trial made; and so on until two temperatures are obtained, differing by 10° C., at one of which inflammation takes place, whilst at the other the dust-cloud passes over uninflamed. The mean temperature is then taken to be the ignition-temperature of the dust under the conditions of the test.

As an example, to render the operation clear, the details of the tests with sugar may be taken.

Ignition-temperature of sugar dust.—The dust was dried and sieved through a sieve with 200 meshes to the linear inch.

Temperature of Coil	*Result*
900° C.	Ignition. Rapid propagation of flame.
880° C.	" " " "
860° C.	" " " "
840° C.	Ignition after an interval.
820° C.	" " "
800° C.	No ignition.
810° C.	Ignition. Rapid propagation of flame.
800° C.	No ignition.

Ignition temperature = 805° C.

When ignition occurs, flame is propagated both with and against the direction of travel of the dust-cloud, and issues in some cases from the open end of the cylinder at a distance of 100 cm. from the igniting coil. With other dusts the flame travels only 50 or 60 cm. along the cylinder; with others, generally those containing a high percentage of mineral matter, a small flare, only, appears in the vicinity of the igniting coil, and no true propagation of flame takes place.

The ignition-temperatures observed, which, it will be understood, are *relative* and refer only to the particular set of experimental conditions employed, are given in the table that follows. For the sake of comparison it may be mentioned that the ignition temperatures of most bituminous coal dusts, as determined in the same apparatus, lie between 1000° and 1100° C.

So far as possible, the different dusts (all of which were dried during one hour at 107° C.) were obtained of the same degree of fineness by passing through a 200-mesh sieve. In some cases this was not possible owing to the fluffy nature of the substance; in other cases the sample received contained no such fine dust. The ignition-temperatures in such cases have no relative value, and the experiments made serve only to show whether or not the substance is dangerously inflammable.

[2] Test No. 2—Determination of the Lowest Temperature at Which Ignition Can Be Effected—now to be described, attempts to determine the lowest temperatures at which ignition can be effected in the case of all the dusts already subjected to Test No. 1.

The igniting-surface in this test is a loosely rolled spiral of copper gauze contained in a porcelain tube (A), of 25 mm. internal diameter and 10 cm. long. This tube is placed vertically as shown in fig. 4. The sieved and dried dust is introduced into the horizontal dust-tube (B); its weight being 0.2 grams. The wide portion of this dust-tube is then placed vertically over the porcelain tube which is heated by a small electric furnace. A tap which connects with the apparatus for giving a constant puff of air, previously described (fig. 3), is now quickly opened. All the dust in the dust-tube is thus projected downwards through the

As a result of these tests, Dr. Wheeler has divided the various dusts into three classes, namely:

Class I.—Dusts which ignite and propagate flame readily, the source of heat required for ignition being comparatively small; such, for example, as a lighted match.

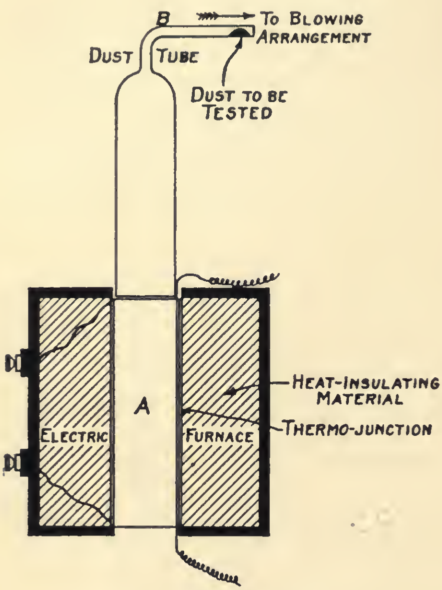

Fig. 4.
Apparatus for Determination of Lowest Ignition Temperature.

Class II.—Dusts which are readily ignited, but which for the propagation of flame require a source of heat of large size and high temperature (such as an electric arc), or of long duration (such as the flame of a Bunsen burner).

Class III.—Dusts which do not appear to be capable of propagating flame under any conditions likely to obtain in a factory; either (*a*) because they do not readily form a cloud in air, or (*b*) because they are contaminated with a large quantity of incombustible matter, or (*c*) because the material of which they are composed does not burn rapidly enough.

As a result of the tests he found it possible to place the various dusts in three classes as follows:

Class I.

Sugar	Unextracted soya bean	Grain (grain storage)
Dextrine (calcined farina)	Wood flour	Rape seed
Starch	Malt	Cornflour.
Cocoa	Oat husk	Flour (flour mill)
Rice, meal and sugar refuse	Grain (flour mill)	Chicory
Cork	Maize	Briquette
	Tea	Gramophone record
	Compound cake	Extracted soya bean

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furnace. If the temperature is high enough it ignites there and a flame appears underneath.

Before making the series of determinations with the different dusts, a series of experiments was made using dust of the same composition and varying the time of passage of the cloud through the tube. This was done by varying the time of fall of the piston in the apparatus for giving a constant puff of air. It was found, as anticipated, that, up to a certain point, the slower the rate of passage of the dust-cloud through the porcelain tube the lower need the temperature of the latter be to cause ignition.

Class II.

Copal gum	Sawdust	Horn meal
Leather	Castor oil meal	Mustard
"Dead" cork	Oil cake	Shoddy
Cocoanut oil milling	Offal grinding (bran)	Shellac composition
Rice milling	Grist milling	

Class III.

Organic ammonia	Retort carbon	Charcoal
Tobacco	Rape seed (Russian)	Foundry blacking
Spice milling	Blacking	Brush carbon
Bone meal	Grain cleaning	Stale coke
Coal (foundry blacking)	Drug grinding	Plumbago
Lamp black	Cotton seed	Bone charcoal
Sack cleaning	Cotton seed and soya bean	Mineral and ivory black

Dr. Wheeler makes the following comments upon the various classes:

"The dusts in Class I are arranged (roughly) in order of their inflammability. In this class, sugar, dextrine, starch, and cocoa[1] are the most dangerous, sugar exceptionally so. Sugar ignites when projected as a cloud against a surface heated to below red heat, and, when ignition has taken place, the flame travels throughout the dust-cloud with great rapidity.

"Of the dusts in Class II the samples of shoddy, being of a fluffy nature, did not readily form a cloud in air, but they contained a sufficient quantity of fine material to render them dangerous when in bulk. The sample of shellac composition contained over 60 per cent. of incombustible matter, but was inflammable; a reduction in the quantity of incombustible matter present would render it dangerous.

"Of Class III the first 10 are all more or less readily inflammable, but they showed no signs of being capable of *propagating* flame. It is possible, however, that other samples of the same materials, less contaminated with incombustible matter, or in a finer state of division, might be found capable of propagating flame. The classification of these dusts as harmless refers, therefore, to the particular samples tested only. The remaining dusts in Class III can be definitely regarded as harmless materials."

In order to determine the temperature of ignition which is necessary to have a propagation through a cloud of the various dusts, a method was devised in which a cloud of dust was blown against a coil of platinum wire, the temperature of which could be measured and easily controlled. The results of these tests with the various dusts already classified above are shown in Table I.

[1] The sample of cocoa dust tested appeared to have had sugar mixed with it.

TABLE I.

Temperature of Ignition of Various Dusts When Small Portions of Cloud Are Instantaneously Heated.

Laboratory Index No. (1)	Substance. (2)	Percentage of sample as received that passed a 200-mesh sieve. (3)	Ignition-Temperature °C. (4)	Remarks. (5)
1	Dextrine (calcined farina).	Practically all passed through.	940	Flame travelled very rapidly in the cloud.
2	Cork	Practically all passed through.	975	Flame travelled rapidly.
3	Wood flour	Fluffy, could not sieve.	985	Cloud formed easily although the sample was unsieved.
4	Lamp black	Could not be sieved.	—	No ignition.
5	Cotton seed			Difficult to form a cloud. Such pieces as came in contact with the coil showed but slight tendency to inflame.
6	Cotton seed and soya bean.	Fluffy, could not sieve.	—	
7	Cotton seed			
8	Compound cake	10	955	Flame travelled rapidly.
9	Rice meal and sugar refuse.	Fluffy, could not sieve.	970	Cloud formed easily and flame travelled rapidly in it.
10	Rape seed	Did not sieve, sample too small.	1050	Ignition-temperature probably lower, but no more dust available.
11	Unextracted soya bean.	10	975	—
12	Rape seed (Russian).	90	—	No ignition.
13	Extracted soya bean.	50	1140	—
14	Castor oil meal.	50	1100	—
15	Grain (flour mill).	50	995	—
16	Tobacco	75		No ignition. A few sparks appeared around the coil above 1100°.
17	Organic ammonia.	10	—	
18	Retort carbon	30	—	No ignition.
19	Spice milling	50		
20	Drug grinding	30		A small flare appeared at the coil at 1000° and upwards, but no flame was propagated.
21	Drug grinding	75	—	
22	Drug grinding	70		
23	Tobacco	75		
24	Leather	30	1050	—
25	Sawdust	20	970	—
26	Grist milling	30	—	A small flare appeared at coil but there was no propagation of flame.
27	Oil cake	30	945	—
28	Sack cleaning	Fluffy, could not sieve.	—	No ignition.
29	Rice milling	20		Small flare at coil but no propagation of flame.
30	Cocoanut oil milling.	None passedthrough sieve.	—	
31	Offal grinding (bran).	75	980	—

TABLE I — *Continued*

Laboratory Index No. (1)	Substance. (2)	Percentage of sample as received that passed a 200-mesh sieve. (3)	Ignition-Temperature °C. (4)	Remarks. (5)
32	Tea..........	50	1010	—
33	Sugar.........	50	805	Flame travelled very rapidly in the cloud.
34	Blacking......	75	—	No ignition.
35	Grain (grain storage).	20	1050	—
36	Starch........	80	1035	—
37	Grain cleaning.	None passed through	—	No ignition. Sample much too coarse to form a cloud.
38	Horn meal.....	50	—	No ignition; a few sparks only.
39	Oat husk......	90	990	—
40	Cork.........	50	990	Flame propagated rapidly.
41	Cork.........	90	1080	—
42	Starch........	100	960	Flame propagated rapidly.
43	Foundry blacking.	100	—	No ignition.
44	Briquette......	90	1090	—
45	Chicory.......	80	1070	—
46	Malt.........	50	990	Flame propagated rapidly.
47	Cocoa........	100	970	Flame propagated rapidly.
48	Mustard......	50	1050	—
49	Shoddy.......	Could not be sieved.	—	No cloud could be formed.
51	Flour.........	90	1060	—
52	Brush carbon..	100	—	No ignition.
53	Maize........	70	1010	—
54	Shellac composition.	100	—	No ignition; a few sparks only.
55	Gramophone record.	100	1100	—
56	Copal gum....	70	1010	Flame propagated rapidly.
57	Charcoal......	90	—	No ignition; a few sparks only.
58	Coal (foundry blacking).	70	—	No ignition; a few sparks only.
59	Stale coke.....	70	—	No ignition.
60	Plumbago.....	95	—	No ignition.
61	Bone meal.....	40	—	No ignition; a few sparks only.
62	Bone charcoal..	100	—	No ignition.
63	Cornflour......	90	1060	—
64	"Dead" cork...	100	1100	—
65	Mineral and ivory black.	100	—	No ignition.

These determinations definitely class dusts Nos. 4, 12, 18, 28, 34, 37, 43, 52, 59, 60, 62, 65 and 66 as harmless dusts, and Nos. 1, 2, 3, 8, 9, 10, 11, 13, 14, 15, 24, 25, 27, 31, 32, 33, 35, 36, 39, 40, 41, 42, 44, 45, 46, 47, 48, 51, 53, 55, 56, 63, and 64 as more or less dangerous, but they leave others doubtful.

The second test, to determine the lowest temperature of ignition of the various dusts, was made by allowing a cloud of dust to fall through a small glass tube heated to a definite temperature, and in which was a small roll of copper gauze. The following determinations (Table II) were then made, the figures indicating the lowest temperatures at which flame appeared at the lower end of the porcelain tube. In a separate column the percentages of incombustible matter present in each dust are given.

TABLE II.

Lowest Ignition Temperatures for Various Dusts When Cloud Is Heated Instantaneously.

Laboratory Index No. (1)	Substance. (2)	Lowest Ignition-Temperature °C. (3)	Percentage of Incombustible Matter. (4)
1	Dextrine (calcined farina)	540	4.2
2	Cork	620	0.6
3	Wood flour	610	3.2
4	Lamp black	No ignition could be obtained	—
5	Cotton seed	No cloud could be formed	7.4
6	Cotton seed and soya bean.	No cloud could be formed	60.5
7	Cotton seed	No cloud could be formed	26.3
8	Compound cake	620	9.3
9	Rice meal and sugar refuse.	630	8.1
10	Rape seed	650	No dust for analysis.
11	Unextracted soya bean	630	12.5
12	Rape seed (Russian)	A few sparks only, obtained at temperatures above 640° C.	72.8
13	Extracted soya bean	630	12.5
14	Castor oil meal	655	23.1
15	Grain (flour mill)	630	18.2
16	Tobacco	680 Very small flame	21.0
17	Organic ammonia	690 Very small flame	12.5
18	Retort carbon	No ignition could be obtained	4.4
19	Spice milling	680 Very small flame	29.9
20	Drug grinding	690 Very small flame	8.8
21	Drug grinding	680 Very small flame	58.7
22	Drug grinding	690 Very small flame	21.3
23	Tobacco	700 Very small flame	31.6
24	Leather	740	14.3
25	Sawdust	635	3.9
26	Grist milling	600	7.8
27	Oil cake	660	27.3
28	Sack cleaning	No ignition could be obtained	74.6
29	Rice milling	630	4.2
30	Cocoanut oil milling	640	5.8
31	Offal grinding (bran)	640	30.0
32	Tea	640	8.3
33	Sugar	540	1.4
34	Blacking	No ignition could be obtained	60.4
35	Grain (grain storage)	630	10.5
36	Starch	640	1.5
37	Grain cleaning	Not tested; dust much too coarse.	8.9

TABLE II — *Continued*

Laboratory Index No. (1)	Substance. (2)	Lowest Ignition-Temperature °C. (3)	Percentage of Incombustible Matter. (4)
38	Horn meal	670	5.3
39	Oat husk	620	13.4
40	Cork	630	1.7
41	Cork	690	2.5
42	Starch	630	0.4
43	Foundry blacking	810 Small flame	10.5
44	Briquette	800 Small flame	9.9
45	Chicory	660	7.5
46	Malt	600	11.7
47	Cocoa	620	8.1
48	Mustard	680	5.1
49	Shoddy	690	15.8
50	Shoddy	610	15.9
51	Flour	650	1.5
52	Brush carbon	No ignition could be obtained	15.2
53	Maize	645	8.0
54	Shellac composition	780 Small flame	61.4
55	Gramophone record	750 Small flame	32.8
56	Copal gum	750	1.8
57	Charcoal	760 Small flame	10.4
58	Coal (foundry blacking)	830 Small flame	21.4
59	Stale coke	No ignition could be obtained	39.7
60	Plumbago	No ignition could be obtained	78.2
61	Bone meal	700	48.0
62	Bone charcoal	No ignition could be obtained	77.0
63	Cornflour	620	0.9
64	"Dead" cork	740	11.6
65	Mineral and ivory black	No ignition could be obtained	23.5
66	Mineral and ivory black	No ignition could be obtained	32.0

These tests again class dusts Nos. 4, 12, 18, 28, 34, 37, 52, 59, 60, 62, 65 and 66 as harmless. To these may be added Nos. 5, 6, 7, 16, 17, 19, 20, 21, 22, 23, 43 and 57; for, just as Test No. 1 showed that no propagation of flame through the dust-cloud could be obtained with these dusts, so in Test No. 2 the flame obtained (at a considerably higher temperature than was required for the remainder of the dusts) was very small and showed no tendency to spread through the dust cloud. At the same time it should be noted that this judgment refers only to the particular samples of dust received, and does not necessarily hold for all samples of the same materials.

In the early investigations of the Bureau of Mines[1] a method[2] was

[1] Bureau of Mines Bulls., 50 and 102.

[2] Description of apparatus used by the Bureau of Mines.

The apparatus is shown in figure 5. It consists essentially of an explosion flask *a*, the platinum coil *i*, and devices for putting the dust in suspension and for measuring the pressure developed in *a*. The flask *a*, which has a capacity of 1600 cc., is provided with large tubulures at its top and bottom; the ends of these

developed in which a cloud of dust was blown up into a glass globe and against a heated coil of platinum wire. The dust was ignited and the pressure generated was determined by finding the weight of mercury which would just be raised by the explosion of a definite weight of the dust. A large number of samples of coal were tested as well as a few samples of other dusts. Some of the results are given in Table III. They show in the reverse order the relative danger of the various dusts. It

tubulures are ground true on a glass plate with emery powder. Experience indicates that a flask with a capacity of about 1,250 cc. would probably be preferable. The brass plate *k*, which rests on the end of the top tubulure, carries the platinum coil *i*, and the brass tube *m*. The brass plate *c*, on which *a* rests, carries the small glass funnel *b*, which is cemented gas-tight into *c*. The contact between the ends of *a* and the brass plates *k* and *c* is made gas-tight by wide rubber bands which are placed around the ends of each tubulure and left projecting a short distance. The contraction of the rubber draws the projecting portion down on the ends, forming a rubber cushion between the ends of the tubulures and the brass plates, and by screwing down the nuts above the steel piece *l*, the joints at these points are made tight. The platinum coil *i* is sus-

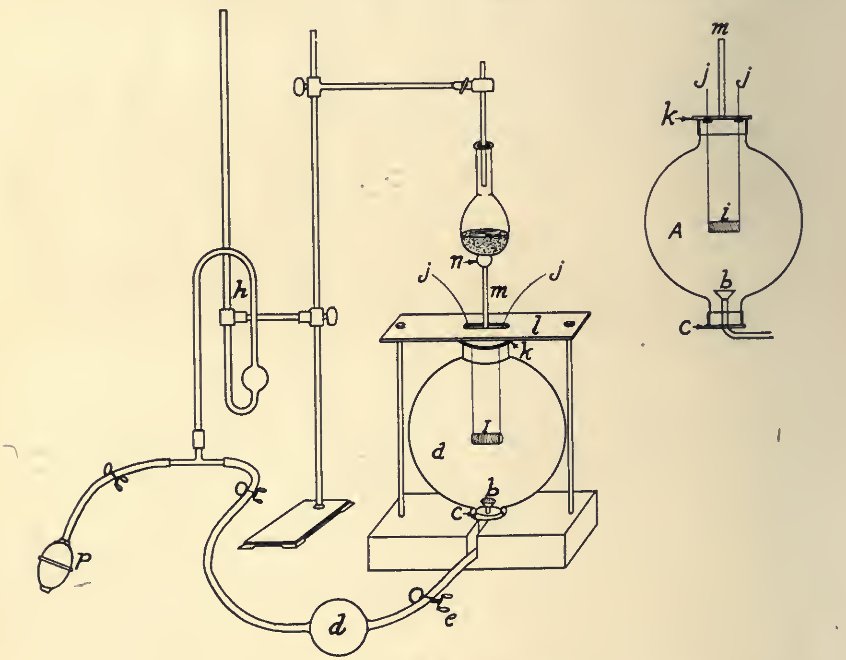

Fig. 5.
Inflammability Apparatus Diagram.

pended near the center of *a* by the two stout nickel leads *j*, *j*, which pass through fibre plugs in *k*. The coil *i* is made of about 100 cm. of No. 26 platinum wire, wound on a quartz-glass frame, which is attached as described above to the leads *j*, *j*. The steel ball *n* is ground to fit practically gas tight on top of *m*, which is soldered to *k* and communicates with *a*.

The dust to be investigated is weighed into the glass funnel *b* and at each

will be noted that most of the coal dusts are less inflammable than the other dusts, and that the most inflammable of all is lycopodium.

The Bureau of Mines and also experiment stations in other countries have made a great number of large-scale tests on coal dusts, either in large steel galleries or in experimental mines. These tests require much time and large quantities of dust. Consequently, to make it possible to test smaller samples and a larger number in a short time, attempts have

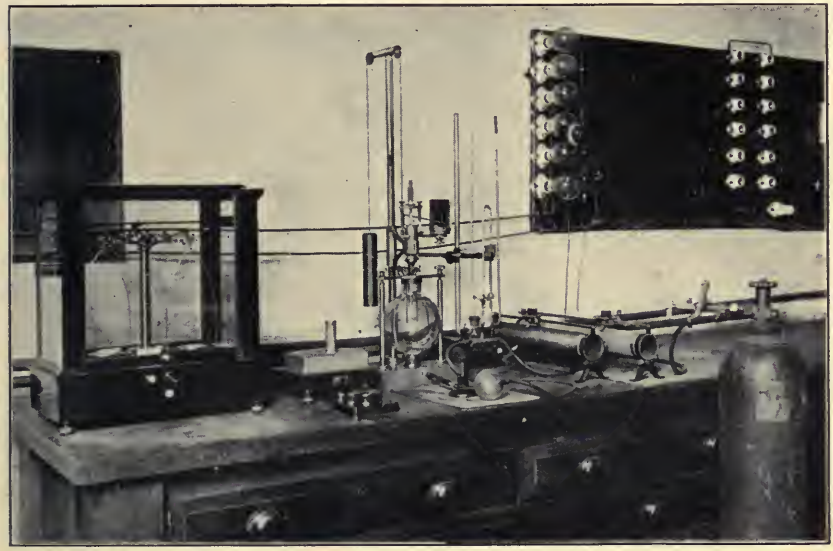

PLATE I.
Inflammability Apparatus as set up in the Laboratory.

been made to develop a laboratory method which would be sufficiently sensitive to test all types of coal dusts and with which it would be possible to obtain some idea of what might be expected if the dusts were tested in the mine.

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trial is brought to about the same position in the stem of the funnel, which is then connected by means of a short rubber tube to the 150-cc. glass bulb *d*. By means of the compression bulb, *p*, the air in *d* is compressed until a pressure of 150 mm. of mercury is indicated by the manometer *h*. At the proper instant the dust in *b* is ejected and put in suspension in *a* by suddenly opening the pinch-cock *e*. In order to insure a more uniform dissemination of the dust in *a*, *b* is covered with a small piece of 18-mesh copper gauze. By blowing the dust through the gauze the adhering particles are more completely separated and the density of the dust cloud in *a* is rendered more uniform. It has been found inadvisable to use the gauze on *b*, except with samples of coal dust. The pressure developed in *a* is determined by ascertaining by several trials the smallest weight that must be placed on *n* to prevent its being lifted from *m*.

TABLE III.

Description.	Chemical analysis (air-dried)							Inflam-mabil-ity.a	Weight lifted at different current strengths.				
	Mois-ture.	Vola-tile matter.	Fixed carbon.	Ash.	Sul-phur.	Oxy-gen.	Nitro-gen.		5.0 amperes.	5.5 amperes.	6.0 amperes.	6.5 amperes.	7.0 amperes.
DUSTS OTHER THAN COAL DUST.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Inverse Order.	Grams.	Grams.	Grams.	Grams.	Grams.
Flour	11.09	63.58	24.90	0.43	......	......	......	1	98	118	148	158	188
Pine dust	4.38	71.92	16.02	7.68	......	......	......	2	13	18	43	178	218
Oak dust	3.22	77.05	16.56	3.17	......	......	......	3	140	143	183	228	238
Asphalt; Oklahoma; Pushmataha County; Jumbo; Jumbo mine	.29	44.67	48.07	6.97	1.60	1.80	1.45	4	105	180	218	235	243
Asphalt; Oklahoma; Pushmataha County; Jumbo; Jumbo mine	.21	43.98	49.19	6.62	1.63	1.85	1.41	5	75	140	220	235	243
Asphalt; Oklahoma; Pushmataha County; Jumbo; Jumbo mine	.34	44.50	48.37	6.79	1.61	1.56	1.44	6	125	178	228	238	243
Starch	14.58	70.21	14.87	.34	......	......	......	7	48	188	228	243	248
Asphalt; Oklahoma; Pushmataha County; Jumbo; Jumbo mine	.24	43.36	50.70	5.70	1.62	2.26	1.39	8	125	170	233	253	258
Sugar	......	95.15	4.85	......	......	......	......	9	268	288	293	298	300
Mahogany dust	5.55	72.71	19.91	1.83	......	......	......	10	138	160	193	288	308
Lycopodium	2.04	87.39	8.98	1.59	.11	......	......	11	400	435	520	530	540
COAL DUSTS.													
Montana, Valley County, 7 miles N. W. of Mondak; outcrop; lignite	12.49	40.65	40.75	6.11	.56	33.45	1.15	1	......	......	5	13	25
West Virginia, Fayette County; Thayer; Slater-Buffalo mine; Fire Creek bed; semibituminous coal	.69	18.93	72.68	7.70	1.10	3.82	1.60	2	......	8	18	48	85
Colorado, Las Animas County; Starkville; Starkville mine; Starkville bed; bituminous coal	1.22	29.23	52.77	16.78	.56	6.81	1.11	3	8	18	28	145	163
Pennsylvania, Washington County; Band Station; Schoenberger mine; Pittsburgh bed; bituminous coal	1.07	34.55	58.51	5.87	1.07	6.97	1.41	4	......	18	33	153	183
Oklahoma, Pittsburg County, 2 miles north of Alderson; Alderson No. 38 mine; McAlester bed; bituminous coal	1.52	33.28	58.04	7.16	.50	8.67	1.65	5	......	15	23	183	203
Pennsylvania, Allegheny County; Bruceton; Experimental mine; Pittsburgh bed; bituminous coal	1.83	35.62	56.69	5.86	1.19	......	......	6	......	53	103	220	233
Utah, Carbon County; Hiawatha; Hiawatha No. 2 mine; Hiawatha bed bituminous coal	3.33	41.79	47.76	7.12	.57	13.89	1.42	7	23	108	133	263	263
Wyoming, Sheridan County; Monarch; Monarch mine; Monarch bed; subbituminous coal	14.97	35.24	46.22	3.57	.41	28.47	1.21	8	......	138	208	253	308

a Materials arranged in the order of their inflammability, the last being the most inflammable, according to weights lifted with greatest current. The relative inflammability of the dusts is based on the results of the tests in which the greatest current strength was on the wire (see p. 18), and the dust least inflammable with that current strength under the conditions of the tests is ranked first in this table.

The Bureau of Mines[1], in later tests, developed a laboratory method[2] which is capable of measuring the inflammability of the least inflammable dusts that will propagate an explosion in the experimental mine. A rela-

[1] Technical Paper 141.

[2] The apparatus used by the Bureau of Mines is shown in Figure 6, and in Plate I. The essential features are the explosion globe *a*, the igniting tube *b*, the pressure recording device *c*, the lifting device *d*, and auxiliary devices for measuring the temperature of the igniting tube and for throwing the dust into suspension.

The explosion globe, capacity 1,400 cc., is fitted with tubulures at its top and bottom. The lower tubulure is provided with a rubber gasket, and the upper

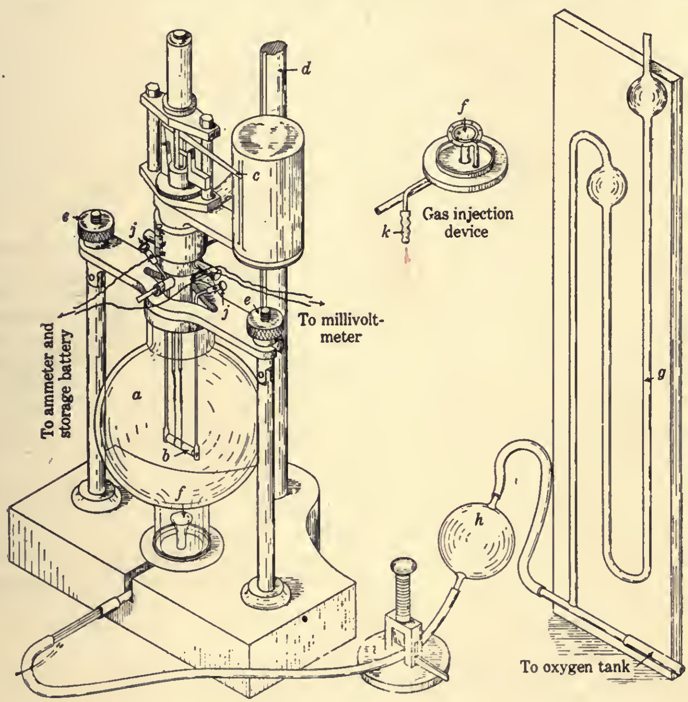

Fig. 6.
Bureau of Mines Inflammability Apparatus.

tubulure presses against a rubber gasket cemented to the head of the apparatus. The joints at the top and bottom of the globe are made gas-tight by screwing down the thumb nuts *e*.

The glass dust injector *f* is the receptacle for the coal dust and is provided with a cap of 14-mesh copper gauze, not shown in the figure. The dust is raised in a cloud by a puff of oxygen.

The oxygen is drawn from a steel cylinder and the puff is controlled by means of a manometer *g*, the reservoir *h*, and the releasing device *i*. The rapidity with which the oxygen forces the dust out of the injection funnel is regulated by a capillary tube, 2 mm. in diameter and 6 cm. long, inserted between the releasing device and the injection funnel.

tion has been established between the results of the tests on a large scale at the experimental mine and the results of the laboratory tests, so that it is now possible to determine from the latter alone whether or not a

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The igniting tube consists of a hardened "lavite" tube on which is wound a heating coil of 0.23 mm. platinum wire, 40 turns to the inch, enclosed in a platinum tube made of 0.1 mm. sheet platinum. On the surface of the "lavite" tube is cut a suitable spiral groove in which the platinum wire is wound. The wire is insulated from the platinum tube by a layer of alundum cement which is baked on. The igniting tube is held in place by platinum leads of 0.4 mm. diameter which are fused to the ends of the heating coil and secured in the binding posts at the lower extremities of the steel leads *j*.

The temperature of the platinum tube is measured by a platinum and platinum-rhodium thermo-couple and a Siemens & Halske millivoltmeter. The ends of the platinum and platinum-rhodium wires, instead of being fused together in the usual manner to form the hot junction, are attached separately to the platinum tube; the platinum-rhodium wire at the middle of the tube and on the front side; the platinum wire about 3 mm. to one side of the platinum-rhodium wire. The point of contact of the platinum-rhodium wire with the platinum tube is therefore the hot junction of the couple. To reduce to a minimum the loss of heat from the tube by conduction along the wires, the ends are drawn down to a diameter of 0.15 mm. The thermo-couple and millivoltmeter were calibrated, and the error of temperature measurement is less than 10° C.

The pressure developed by the explosion is measured by a Crosby gas and steam engine indicator. Inasmuch as only the maximum pressure is desired, the drum is ordinarily not rotated. Preliminary experiments in which the drum was rotated at a speed of 140 to 200 revolutions per minute showed that the inertia of the moving parts was not great enough to prevent the gage from correctly indicating the pressure developed. The pressure curve rose rapidly to a maximum from which it dropped very slowly.

For experiments in an atmosphere containing a small percentage of combustible gas a base plate, provided with a brass tube *k* (fig. 6) for introducing the combustible gas, is used. The gas enters the bulb through eight small holes in the wall of the circular part of the tube.

Method of Operation. A weighed quantity of the dust to be tested is poured into the glass funnel *f* (fig. 6) and by tapping is brought into position in the funnel stem. The apparatus is then connected as shown in Figure 6 and a current of two amperes taken from a storage battery is passed through the heating coil for one minute, after which the current is increased so as to obtain the desired temperature and continued for four minutes. The pressure of the oxygen in reservoir *h* is adjusted to 15 or 20 cm. of mercury, according to the quantity of dust to be used.

At the end of the five-minute period the vent in the head at the top of the explosion flask is closed with a spring clip, the rubber tube leading into the oxygen reservoir is closed immediately at the entrance of the reservoir by means of a pinch cock, and then the piston of the releasing device is allowed to spring up. A touch on the lever at the right of the piston permits this action. The dust is injected into the explosion globe and is ignited by contact with the igniting element.

In regular work two explosion globes are employed. While one is used in a test, the other is blown out with a blast of air, which renews the atmosphere in the globe and cools the globe itself.

The pressure shown by the Crosby indicator is corrected for the increase due to the injected oxygen by deducting the pressure observed when no dust is used. The pressure reported is always the average of at least three determinations.

The pressures developed vary from a few tenths of a pound with anthracite or with dust very high in ash, to 20 pounds with sub-bituminous coals. Coals of the Pocahontas type give pressures varying from 6 to 10 pounds, and the typical

given dust may give rise to or propagate explosions. The apparatus is similar in some ways to the one first developed in that the dust is injected as a cloud up into a glass globe against a heated coil, and the pressure developed by the ignition is measured. However, instead of air, oxygen is used to inject the dust into the globe, and the pressure developed is measured by a standard type of steam-pressure gauge. The apparatus is also adaptable for testing the inflammability of the dusts in atmospheres containing various percentages of inflammable gases. The results of tests show very conclusively that when a small amount of natural gas is present the coal dust is much more easily ignited, that is, more inflammable. The relative inflammability is measured by the pressure developed in the explosion—the higher the pressure, the more inflammable the dust. A few typical results selected at random are given in Table IV.

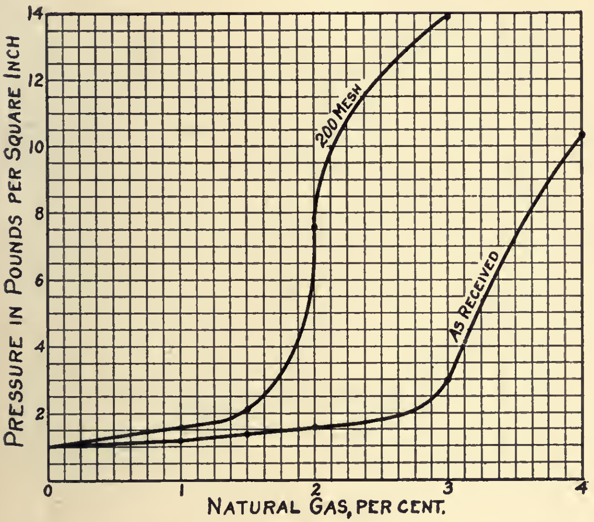

Fig. 7.
Effect of Presence of Gas On Inflammability of Dust.

It will be noted that some of these dusts closely resemble the coal dusts

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Pennsylvania bituminous coals, such as those of the Pittsburgh bed, give pressures of 11 to 15 pounds.

The maximum difference between individual determination on the same sample of dust is usually not over 2 pounds for dusts that develop 10 to 15 pounds pressure. Averages determined by different observers or by the same observer on different days agree ordinarily within 0.5 pound. The greater the deviation between individual observations the larger the number of determinations required.

Usually the quantity of dust used in an experiment is 100 mg. For dusts of low inflammability the amount is 300 mg. With the former quantity of dust the pressure of the oxygen used to eject the dust is 15 cm. and with the latter quantity 20 cm. of mercury. Unless otherwise stated, the tests recorded are made with 200-mesh air-dried samples.

When tests are to be made with a small percentage of combustible gas present in the bulb, the igniting element is raised above the top of the bulb and heated to the proper temperature. The top tubulure is closed and a measured volume of gas introduced into the bulb. At the close of the five minute interval the head of the apparatus is quickly lowered and fixed in position and the dust injected into the globe. As this operation consumes not over five seconds, the composition of the gas is not appreciably changed before the dust is injected.

TABLE IV.

INFLAMMABILITY OF DUST PREPARED FROM FACE SAMPLES.

(SAMPLES AIR DRIED.)

State.	County.	Coal bed.	Kind of coal.	Proximate analysis.			Ash.	Oxygen.	Calorific value of coal.	Inflammability
				Moisture.	Volatile matter.	Fixed carbon.				
				Per cent	Per cent	Per cent	Per cent	Per cent	B. t. u.	Pounds per square in.
Wyoming	Monarch	Monarch	Sub-bituminous	9.68	39.97	44.72	5.63	23.30	11,036	18.0
Utah	Carbon	"Hiawatha"	Bituminous.	3.77	43.71	46.46	6.06	13.83	12,998	17.3
Indiana	Vanderburgh.	No. 5	Bituminous.	2.15	38.60	48.20	11.05	10.48	12,395	15.9
Oklahoma	Pittsburg	Lower Hartshorne	Bituminous.	1.66	38.94	52.74	6.66	7.54	13,822	14.5
Pennsylvania	Allegheny	Pittsburgh	Bituminous.	1.10	35.93	57.47	5.50	....	14,117	13.6
Colorado	Las Animas.	"Cokedale".	Bituminous.	.68	26.42	54.95	17.95	5.77	12,407	12.3
West Virginia.	Fayette	Fire Creek	Semi-bituminous	.49	21.06	71.45	7.00	2.55	14,501	9.1
Pennsylvania	Dauphin	Lykens	Anthracite	.43	9.39	81.49	8.69	....	13,999	1.0

300 mg. used for test.

given in Table III, and tested by the former method. A comparison of the methods can be made by a study of these results. The dusts stand in about the same order, indicating that both methods classify the dusts similarly. The advantages of the latter method are that it is more convenient and accurate and that it has a wider range.

The effect of the presence of small amounts of inflammable gas is shown in Figure 7. It will be noted here that its effect upon the inflammability of the dust depends largely upon the condition of the dust. It should not be considered, however, that all of this difference is due to the effect of the gas, since one sample contains only dust that will pass through a 200-mesh sieve while the other contains some (the percentage is not specified) larger particles. Some of the difference in pressure may be attributed to this fact. This will be discussed later in this chapter.

As all of these methods except the last, which was in process of development, were available at the time the investigation of dust explosions other than coal dust was started, an attempt was made to utilize either the methods themselves or modifications of them. However, those of Taffanel and of Wheeler, which seemed the most promising, were discarded after several tests as unsatisfactory for what was desired. Although the tests made with the Bureau of Mines apparatus gave promise, the results were not altogether satisfactory. Consequently experiments were started which led to the development of a method very similar to that finally adopted by the Bureau of Mines for testing coal dusts, the chief differences, outside of a few minor ones in construction of apparatus[1], being that only 75 mg. of dust are used and that this is injected into the apparatus by means of air instead of oxygen, the air being at 20 cm. of mercury pressure.

This method was used in testing the relative inflammability of a large number of dusts other than coal dust. The results, as given in Table V, show that the most inflammable dust is the one which gives the highest pressure, the relative danger decreasing somewhat with the decreasing pressure.

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[1] The conditions of apparatus and test as used for determining the relative inflammability of dusts other than coal are as follows: Temperature 1200° C., capillary 6 cm. long and 2.0 mm. bore; air under 20 cm. pressure; no one-way valve between the air reservoir and the explosion flask, but a pinch-cock back of the air reservoir; 75 mg. of material; a coarse screen (14-mesh) over the funnel except when very fibrous dust is tested when no screen is used; and a funnel 4.0 mm. internal diameter, with a bowl ¾ in. deep and ⅝ in. across at the top, and the bend in the funnel being at a right-angle ⅝ in. below the bowl and having a small wire screen inside and just back of the bend.

The same type of apparatus as shown in Figure 6 and Plate I, except in the construction of the funnel, is used in testing both the coal and other dust. The difference in conducting the tests consists in using 75 mg. of dust instead of 100 or 300 mg., and this dust is blown into the explosion flask by air under 20 cm. of mercury pressure instead of by oxygen at 15 or 20 cm. pressure of mercury, depending upon the amount of dust used.

TABLE V.

INFLAMMABILITY OF CARBONACEOUS DUSTS.

(Arranged in approximate order of inflammability.)

KIND OF DUST[1]	Pressure Generated Pounds per Square Inch
Lycopodium[2]	17.5
Stinking smut of wheat[2]	15.9
Yellow corn dust from first break in dry milling[2]	15.2
Dextrine dust from dextrine kiln[2]	14.6
Powdered wheat starch[2]	14.0
Stinking smut of wheat with wheat dust[2]	13.9
White dextrine[2]	13.9
Starch dust (corn) dry starch kilns[2]	13.8
Canary dextrine[2]	13.8
Tan bark dust	13.3
Powdered cornstarch[2]	13.2
Wheat starch[2]	13.1
Finished dextrine from reels	13.1
Starch and dextrine dust from about tray filler[2]	13.0
Wheat elevator dust, side wall	13.0
Dextrine dust from top of reels and mixer[2]	12.8
Wood dust from chipper room	12.8
Durum wheat dust from side walls and floor of bin	12.8
Flour dust from roll cyclone	12.7
Tailings from cornstarch mill	12.7
Oat and corn dust from unloading station	12.6
Wheat dust from first break roll	12.6
Lump cornstarch pulverized to pass 200-mesh[2]	12.5
White corn dust, top of elevator[2]	12.5
Wheat elevator dust	12.5
Alkaline starch dust from reel	12.5
Acid starch from reels	12.5
Oat and corn dust, top of elevator[2]	12.4
Wheat dust from first separator	12.4
Starch dust from ledges in grinding and reel room	12.4
Oat dust from ground oat hulls[3]	12.3
Sugar, lump pulverized to pass 200-mesh[2]	12.2
Gluten feed dust, from beams, etc., in curing room[2]	12.1
Rye dust on top of scourer	12.1
Dust from roll dust collectors	12.1
Dust from first break roll in rye mill	12.1
Oat dust from feed oats	12.0
Wheat dust from basement near outlet spouts of bins	12.0
Wheat and oat dust from elevator	12.0
Dust from bran machine after washing and tempering wheat	12.0
Sugar dust collected in cooling bins	12.0
Flour dust from roll suction	11.9
Dust from linseed meal	11.9
Dust from grinding wheat screenings	11.9
Barley malt flour from first break rolls	11.9
Dark canary dextrine[2]	11.8
Feed dust from dust collector	11.8
Dust from under first break flour rolls	11.8
Sugar dust from bins	11.8
Sugar dust from cooling bins above sugar bins	11.8
Potato flour[2]	11.7
Sugar dust from sugar pulverizer[2]	11.7

KIND OF DUST[1]	Pressure Generated Pounds per Square Inch
Feed dust from floor	11.7
Linseed meal, fine	11.7
Sugar dust from collector from sugar bins	11.6
Dust from middling purifiers	11.5
Composite dust from purifiers	11.5
Wheat elevator dust from beams and rafters on bin floor	11.5
Rice starch[2]	11.3
Dust in bolters	11.3
Wheat flour from packing room	11.2
Dust from dust collector from second scourer	11.2
Flour dust from fifth break rolls	11.2
Wheat dust from first scourer	11.2
Flour dust from under collector from rolls	11.2
Dust from cleaning wheat and barley	11.1
Powdered wheat starch[2]	11.0
Corn elevator dust	11.0
Rye dust from suction from elevator head	11.0
Dust from conveying cooked wheat cereal	11.0
Dust from grinding cooked wheat and barley cereal	11.0
Dust from conveying cooked corn flakes	10.8
Wheat dust	10.7
Malt dust from discharge of collecting system[2]	10.6
Wheat dust from cyclone collector	10.6
Wheat flour dust, rolls and purifiers[2]	10.5
Fertilizer dust. from grinding dry tankage	10.5
Dust from collector from handling cooked cereal	10.5
Wheat dust from second scouring	10.5
Wheat dust from third scouring	10.5
Dust from collector from grinding wheat screenings	10.5
Tapioca flour[2]	10.4
Sugar dust, collector from powder mills[2]	10.3
Barley and wheat flour dust, mixed	10.3
Wheat, corn and rice flour, mixed	10.3
Rye dust from inside second break rolls	10.2
Pittsburgh standard coal dust[2]	10.1
Rice polish from polisher	10.1
Tan bark dust[2]	10.0
Dust from unloading wheat	10.0
Dust from bins in starch receiving room	10.0
Dust from pipes in lump starch grinding room	10.0
Tapioca flour[2]	9.9
Cocoa dust from cocoa bolters[2]	9.9
Rice meal from toasted rice flakes	9.9
Dust from roasted wheat	9.9
Dust from dust collector in dextrine cooker room	9.9
Wheat dust from separators	9.7
Sugar dust from ledges near drier	9.5
Reduction middlings[2]	9.4
Dust from feed bins	9.4
Wheat flour from packing room[2]	9.3
Rice polish dust from collector around polisher	9.3
Dust from dextrine cooker room	9.3
Cocoa dust from cocoa cooling room[2]	9.1
Dust from conveying uncooked rice flakes	9.1
Dust from uncooked corn flakes	9.1
Rice starch[2]	9.0
Dust from handling flax	9.0

KIND OF DUST[1]	Pressure Generated Pounds per Square Inch
Wheat dust from cyclone collector	9.0
Wheat dust from tripper of conveyor	9.0
Barley dust from screenings	9.0
Dust from ledges, lump starch	9.0
Malt dust from elevator	8.9
Dust from roasted bran	8.9
Rice dust from cyclone from polisher	8.9
Extra fine sulphur flour[3]	8.8
Wheat smut and field dust[2]	8.8
Wheat screenings from first screen	8.8
Wheat screenings from second screen	8.7
Rice bran dust	8.7
Wheat dust from top of elevator	8.6
Wheat dust from cyclone dust collector	8.6
Dust from cooked wheat and barley cereal	8.5
Dust from cereal coffee	8.5
Wheat and barley dust from cleaning room[2]	8.1
Starch dust from shakers	8.1
Barley dust	8.0
Wheat screenings separating trash, oats and seed	8.0
Rice dust from cleaning	7.9
Barley dust from first screenings, wind separation	7.5
Winter and durum wheat dust	7.5
Ground cork dust[2]	7.4
Rice dust	7.1
Oat elevator dust	7.1
Cooked white corn dust	7.1
Powdered milk	7.1
Wheat elevator dust from receiving separator	7.0
Dextrine dust from bins in reel room	6.5
Barley dust in cleaning barley	6.3
Cooked white corn dust	6.1
Barley dust from dust house	6.1
Alfalfa dust	6.0
Rice flour[2]	5.6
Barley dust from elevator floors	5.5
Wheat elevator dust from conveyor belt	5.0
Barley dust from dust house	4.9
Rice dust from shaker	4.8
Rice dust from bins above cyclone from receiving aspirator	4.8
Alfalfa dust	4.3
Arrow-root powder	3.9
Rice dust from clippers	3.9
Charcoal dust as received	3.6
Potato starch	3.2
Flax dust from cleaning flax	3.2
Gelatine dust from elevator	1.1

[1]All of the samples were run through a 200-mesh screen except as designated.
[2]Unscreened.
[3]100-mesh screen.

These results cannot be considered as absolute, that is, as showing that the order as given here is the exact order of the ease with which these dusts will ignite. It is, however, the order of inflammability as given under the conditions used in the tests. A change of any of the conditions

might increase the pressure given by some, while it would decrease the pressure given by others. This is clearly brought out by tests made upon some of the same dusts during the development of this method but under somewhat different conditions. A comparison is shown in Table VI.

It will be noted that the dusts do not stand in the same order of inflammability in the second column as in the first, and that the differences in the third column are even more marked. For instance, dark canary dextrine, which stands seventh in the first column, is third in order of inflammability in the second column, and is fifth in the third column; while stinking smut of wheat, which is first in both the first and second columns, is last in the third column. It is hard to state, in the light of our present knowledge just what these differences mean, except that the dust is more easily ignited at the temperature and under the conditions of the tests. The position of stinking smut of wheat in the last column is confusing when the fact is considered that it was possible to ignite it

TABLE VI.

Effect of Ignition Temperatures on Inflammability.

Kind of Dust.	Pressure, pounds per square inch. Standard method. 1200° C.	Modified method 1200° C.	800° C.
Stinking smut of wheat	15.9	21.4	0.6
White dextrine	13.9	15.5	7.6
Canary dextrine	13.8	14.9	7.9
Wheat starch	13.1	14.1	8.5
Cornstarch	12.7	12.6	6.7
Sugar, lump pulverized to pass 200-mesh	12.2	13.0	7.5
Dark canary dextrine	11.8	15.1	7.3
Potato flour	11.7	10.4	6.2
Rice starch	11.3	12.3	5.3

with a very small source of ignition. (See chapter on Static Electricity, and on Thresher Explosions.) Just what difference a few pounds in pressure in the vicinity of 10-15 pounds means cannot be explained satisfactorily with the limited facts available. It cannot be said that a dust giving 15 pounds pressure in the tests is really more dangerous than a dust which gives only 12 pounds, but it would be most reasonable to expect that a dust which gives only 9-10 pounds pressure is not as easily ignited as a dust that will give a pressure of around 15 pounds.

It will be noticed, also, that Pittsburgh standard coal dust appears in Table V with a pressure of 10.1 pounds. This same dust gave 13.6 pounds pressure under the conditions of the Bureau of Mines tests, and it is considered to be one of the more inflammable coal dusts. The difference is due largely to the use of oxygen instead of air in injecting the dust into the explosion flask or globe. Many other dusts can be classified as more inflammable than Pittsburgh coal dust, and a number are less inflammable. However, these are only the results for the samples tested, and it is possible that others from the same place in the mill, taken at

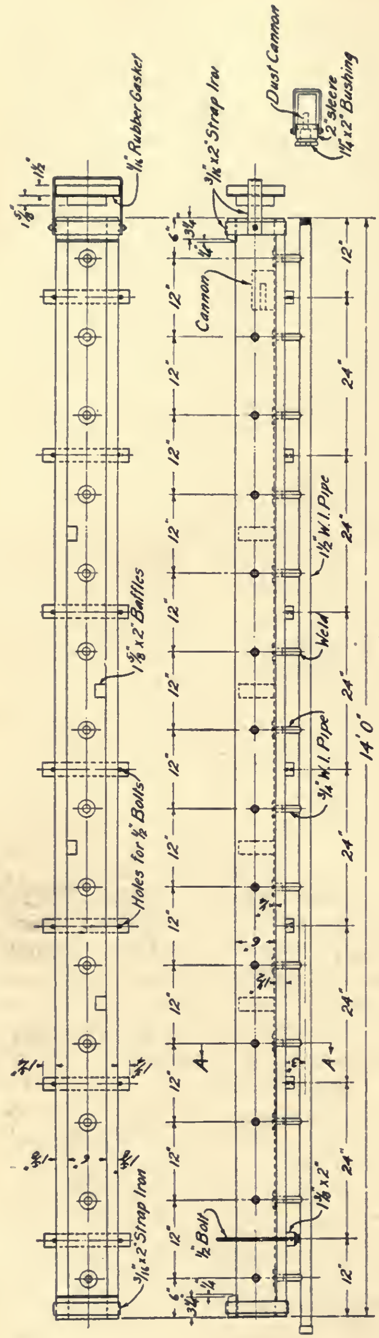
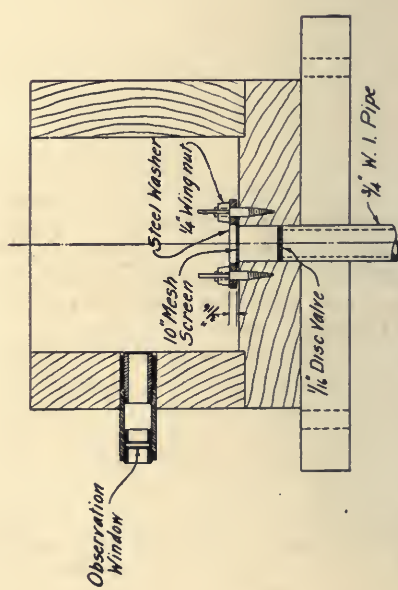


Fig. 8.
Horizontal Gallery for Testing the Explosibility of Dust.



Enlarged Section on A-A.

another time and under slightly different operating conditions, would be much more inflammable. For instance, one sample of rice starch gave 11.3 pounds pressure while another sample of the same material from another source gave only 9.0 pounds pressure. Consequently, it may be considered that practically all of these dusts have, or under some conditions may have, a high degree of inflammability, and that a dangerous condition exists where a cloud of any one of them is in suspension, or where it may be easily thrown into suspension. The relative degree of danger is approximately in the order shown in Table V.

Believing that large-scale tests more closely represent what might be expected in actual operating conditions and desiring to simulate these conditions as nearly as possible, the Bureau of Mines for some time has been working upon the development of a small gallery for making laboratory tests. One gallery which has been used is shown in Figure 8. It is constructed of wood and is 14 feet long and six inches square inside. A dust cloud is formed in the gallery[1] and then ignited at one end by firing a small amount of loose black powder at the closed end. The propagation of the flame was observed through observation windows at the side but it was shown more accurately by placing small pieces of gun cotton on both the roof and floor of the gallery at one-foot intervals, the first being 6 inches inside the open end. As the flame reached the cotton it was ignited, and the number of pieces left unburned showed how far the flame had propagated.

This apparatus was used to test several different carbonaceous dusts, separately and also when mixed with the inert shale dust.

The results of these tests are shown in Table VII. It will be noted that mixtures of 40 per cent flour and 60 per cent shale, of 30 per cent starch and 70 per cent shale, of 30 per cent rice flour and 70 per cent shale, of 20 per cent sulphur and 80 per cent shale, and 80 per cent of one wheat dust and 60 of another, with the balance shale dust, gave results similar to those obtained with coal dust. With slightly higher percentages of shale than these no propagation was obtained. Some dusts, as for instance alfalfa and flax, which on account of their coarseness could not be tested in the ordinary laboratory apparatus, were easily ignited in these tests. A sample of potato starch which showed negative results in the laboratory apparatus gave a very forceful explosion in the small gallery.

[1] In Figure 8 a cross section of the gallery is shown, with an opening in the bottom, into which the dust was placed on the metal disc. The top of the opening was covered with a screen to spread the dust as it was forced up into the gallery. The metal disc rested on the top of a ¾-inch pipe which extended 3 inches below the bottom of the gallery and was welded into a 1½-inch pipe extending the length of the gallery. It was closed at one end and had a small cannon attached at the other. There were 14 of these holes, a foot apart, along the bottom of the gallery. Four grams of the dust were placed in each hole, or a total charge of 56 grams. The percussion and pressure in the pipe from the discharge of the small cannon forced the dust into the gallery, while the small discs stopped the passage of any flame from the discharging powder into the gallery.

TABLE VII.

INFLAMMABILITY OF DUSTS AS TESTED IN HORIZONTAL EXPLOSION GALLERY.

Test No.	Material.[2]	Gallery.	Loose igniting powder in grams.	Flame or gun cottons left.	Remarks.	Shots[1] time interval in seconds
15	Shale dust.........	Open at end..	10 gms.	6 g. c. on top.... 5 g. c. on bottom	....	3 s
53	Shale..............	Open at end..	8 gms.	All of 6 gun cottons left.	....	3 s
54	Nothing...........	Open at end..	8 gms.	5 g. c. top and bottom.	....	3 s
27	Pure 200-m. std. Pitts. coal.	Open at end..	5 gms.	2 g. c. on top.... 2 g. c. on bottom	Standard..........	3 s
9	75% coal........ 25% shale........	Open at end..	10 gms.	No flame visible g. c. gone.......	....	3 s
11	60% coal........ 40% shale........	Open at end..	10 gms.	2 g. c. left..........	....	3 s
12	60% coal .... 40% shale........	Board with 4″ hole on end.	10 gms.	3 g. c. on top.... 6 g. c. on bottom	....	3 s
59	85% std. coal. .... 15% shale........	Open at end..	8 gms.	2 g. c. top and bottom.	....	3 s
1	Flour..............	Open at end..	10 gms.	Flame not through. ..	Did not dust....... (5 gms. of powder used in raising dust cloud)	2 s
2	30% shale........ 70% flour........	Open at end..	10 gms.	Through...........	....	2 s
3	40% shale........ 60% flour........	Open at end..	10 gms.	2 g. c. left..........	....	2 s
4	40% shale........ 60% flour........	Open at end..	10 gms.	Through...........	1 g. shot missed fire. Fired later	15 s
5	50% flour........ 50% shale........	Open at end..	10 gms.	1 g. c. left..........	....	2 s
6	50% flour........ 50% shale........	Open at end..	10 gms.	2 g. c. left..........	....	1 s
7	50% flour........ 50% shale........	Open at end..	10 gms.	Through...........	....	3 s
24	50% flour........ 50% shale........	Open at end..	5 gms.	Flame just out end...	....	3 s
13	40% flour........ 60% shale........	Board with 4″ hole on end.	10 gms.	5 g. c. on top.... 6 g. c. on bottom	....	3 s
23	40% flour........ 60% shale........	Open at end..	10 gms.	Flame just out... 1 g. c. on bottom	....	3 s
25	40% flour........ 60% shale........	Open at end..	5 gms.	2 g. c. on top.... 3 g. c. on bottom	Like coal..........	3 s
26	30% flour........ 70% shale........	Open at end..	5 gms.	4 g. c. on top.... 4 g. c. on bottom	....	3 s
29	60% starch....... 40% shale........	Open at end..	5 gms.	Way out...........	....	3 s
8	50% starch....... 50% shale........	Open at end..	10 gms.	Way out end........	....	3 s
16	50% starch....... 50% shale........	Board with 4″ hole on end.	10 gms.	2 g. c. on top.... 3 g. c. on bottom	....	3 s
14	40% starch....... 60% shale........	Board with 4″ hole on end.	10 gms.	2 g. c. on top.... 3 g. c. on bottom	....	3 s
17	40% starch....... 60% shale........	Open at end..	10 gms.	Flame way out end...	....	3 s
20	40% starch....... 60% shale........	Open at end..	5 gms.	Flame way out end...	....	3 s
18	30% starch....... 70% shale........	Open at end..	10 gms.	Flame way out end...	....	3 s
21	30% starch....... 70% shale........	Ope' at end..	5 gms.	2 g. c. on top.... 2 g. c. on bottom	Like coal..........	3 s
30	30% starch....... 70% shale........	Open at end..	5 gms.	1 g. c. on top.... 1 g. c. on bottom	Like coal..........	3 s
19	20% starch....... 80% shale........	Open at end..	10 gms.	Flame way out end...	....	3 s
22	20% starch....... 80% shale........	Open at end..	5 gms.	5 g. c. bottom ... 5 g. c. top	....	3 s
31	Pure starch[3]........	Open at end..	5 gms.	Flame way out	....	3 s
28	Potato starch 28-A..	Open at end..	5 gms.	Way out...........	....	3 s
32	Rice dust No. 1, 50%, 50% shale.	Open at end..	5 gms.	3 g. c. on top.... 4 g. c. on bottom	Like coal..........	3 s
37	Rice flour, pure, 30-A.	Open at end..	5 gms.	2 g. c. on top.... 1 g. c. on bottom	Like coal; did not dust well.	3 s
38	70% rice flour..... 30% shale........	Open at end..	5 gms.	Flame 4′ out........	....	3 s
41	60% rice flour..... 40% shale........	Open at end..	5 gms.	2 g. c. on top.... 2 g. c. on bottom	Like coal..........	3 s
39	40% rice flour..... 60% shale........	Open at end..	5 gms.	Flame out end.......	Like coal; did not dust well.	3 s

TABLE VII — *Continued*

Test No.	Material.[2]	Gallery.	Loose igniting powder in grams.	Flame or gun cottons left.	Remarks.	Shots[1] time interval in seconds
55	30% rice flour..... 70% shale........	Open at end.	8 gms.	2 g. c. top and bottom.	Like coal..........	3 s
33	Cyclone rice dust ..	Open at end..	5 gms.	2 g. c. on top........	Like coal; holes not emptied.	3 s
34	Cyclone rice dust ...	Same; no screens.	5 gms.	2 g. c. on bottom	....	3 s
40	No. 7 200-m. rice dust.	Open at end..	5 gms.	Flame out end.......	Like coal; did not dust well.	3 s
42	No. 8 200-m. rice dust.	Open at end..	5 gms.	2 g. c. on top.... 3 g. c. on bottom	Like coal..........	3 s
35	Alfalfa No. 1, pure ..	Open at end..	5 gms.	1 g. c. on top.... 1 g. c. on bottom	Like coal..........	3 s
43	Misc. 5510 alfalfa meal.	No screens....	5 gms.	3 g. c. on top........	Not quite as inf. as coal.	3 s
44	Misc. 5481 alfalfa meal.	No screens....	10 gms.	Flame out end.......	(5 gms. of powder used in raising dust cloud).	3 s
73	90% alfalfa ...... 10% shale, 200-m.	Open at end..	8 gms.	1 g. c. top and bottom.	Like coal..........	3 s
36	Corn dust fromaround grate.	No screens ...	5 gms.	Big volume flame	....	3 s
51	50% corn elev. dust 50% shale........	Open at end..	5 gms.	Flame to end........	....	3 s
52	30% corn elev. dust 70% shale........	Open at end..	5 gms.	3 g. c. on top.... 3 g. c. on bottom	40% corn elev. like coal.	3 s
45	No. 5 wheat dust from milling separator.	No screens....	5 gms.	Flame way out end...	(5 gms. of powder used in raising dust cloud.)	3 s
61	Wheat dust........	Open at end..	8 gms.	3 g. c. left..........	....	3 s
62	Wheat dust, first floor leg	Open at end..	8 gms.	1 g. c. left..........	....	3 s
64	Wheat dust, top elevator.	Open at end..	8 gms.	3 g. c. left..........	....	3 s
70	No. 3 wheat dust from cupola.	Open at end..	8 gms.	4 g. c. left..........	Like coal..........	3 s
72	80% wheat dust... 20% shale, 200-m..	Open at end..	8 gms.	2 g. c. top and bottom.	Like coal..........	3 s
75	60% wheat dust... 40% shale, 200-m..	Open at end..	8 gms.	2 g. c. top and bottom.	Like coal..........	3 s
69	Dead elev. dust, St. Louis.	Open at end..	8 gms.	3 g. c. left..........	Like coal..........	3 s
46	50% tapioca flour 29-A. 50% shale........	Open at end..	5 gms.	Flame out..........	Like coal..........	3 s
47	40% tapioca flour . 60% shale........	Open at end..	5 gms.	1 g. c. on top.... 1 g. c. on bottom	....	3 s
48	Sulphur, pure.......	Open at end..	5 gms.	Very violent.........	....	3 s
49	50% sulphur ..... 50% shale........	Open at end..	5 gms.	Very violent.........	....	3 s
50	30% sulphur .... 70% shale........	Open at end..	5 gms.	Flame 1 — 2′ out.....	....	3 s
56	20% sulphur .... 80% shale........	Open at end..	8 gms.	2 g. c. on top.... 3 g. c. on bottom	Like coal..........	3 s
57	Flax dust..........	Open at end..	8 gms.	1 g. c. on top........	....	3 s
58	Barley dust........	Open at end..	8 gms.	1 g. c. on top........	Both shots fired together — like coal.	3 s
71	50% barley dust. . 50% shale........	Open at end..	8 gms.	1 g. c. left..........	Like coal..........	3 s
65	Mixed oats, wheat and barley.	Open at end..	8 gms.	1 g. c. left..........	....	3 s
60	Sweepings, elev.	Open at end..	8 gms.	3 g. c. left..........	Like coal..........	3 s
63	Old dust, top elev.	Open at end..	8 gms.	Flame just out.......	....	3 s
66	Dust from seed cleaning house.	Open at end..	8 gms.	1 g. c. left..........	....	3 s
67	Dust from grinding peas.	Open at end..	8 gms.	1 g. c left	....	3 s
68	75% pea dust .... 25% shale........	Open at end..	8 gms.	1 g. c. left..........	....	3 s

NOTE: 2.5 gms. of powder were used to raise dust cloud, except as otherwise listed under Remarks.

[1] Number of seconds between firing of shot to form cloud and time of igniting of the cloud.

[2] A loading of 4 gms. of material per hole in each test.

[3] 1.2 gm. per hole. Same amt. as in shale mix.

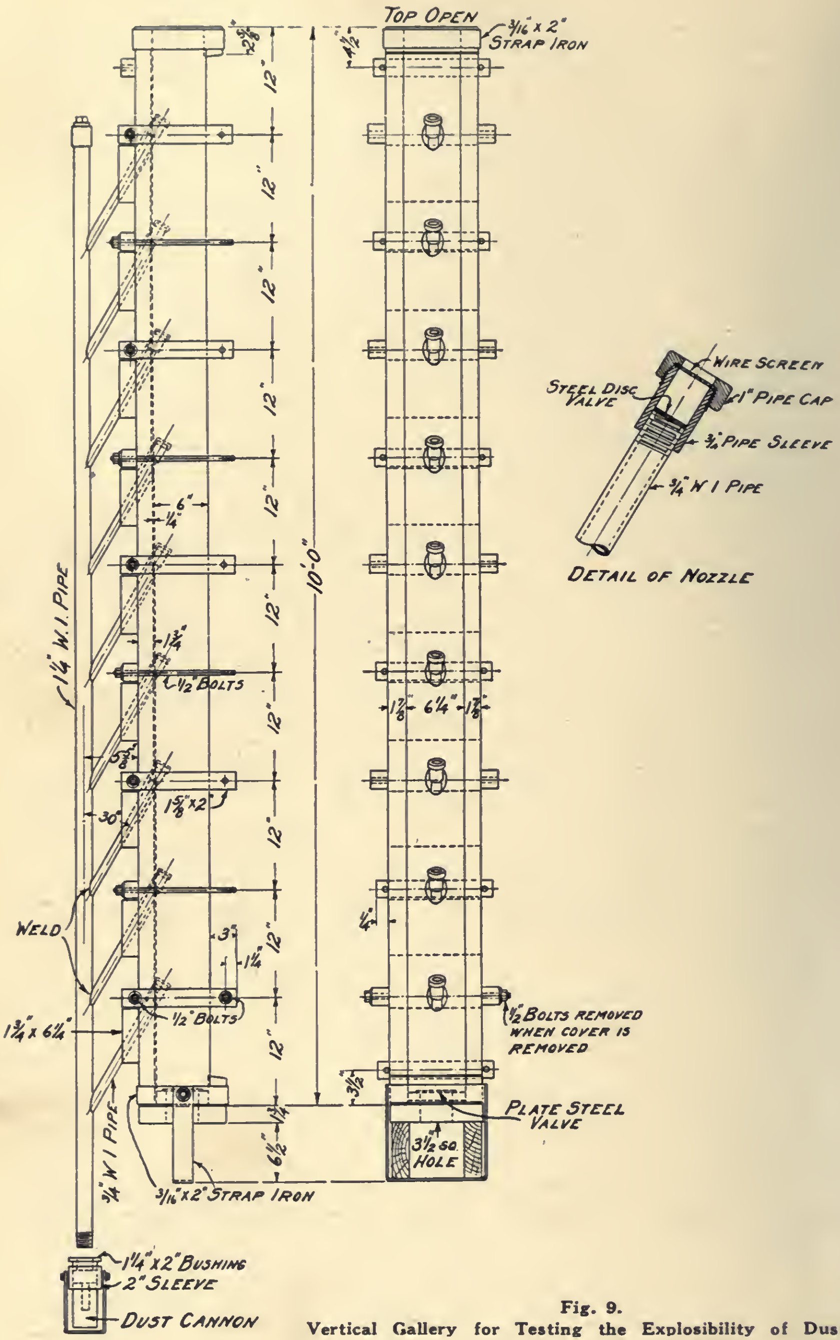


Fig. 9.
Vertical Gallery for Testing the Explosibility of Dust.

With this gallery it was possible to obtain a good and uniform dust cloud, but it would settle quickly. It was thought that a condition more nearly simulating factory conditions would be obtained in a vertical gallery where a column of the dust cloud could be obtained of such a height that it would take some time to settle and so, if too dense at first, it would gradually pass through the explosive limits. Consequently, a vertical gallery (fig. 9 and Plate 2) 10 feet high and 6 inches square on the inside was made. The dust was injected as in the horizontal gallery, by the discharge of a little black powder, but it was ignited by an arc or an open flame, sources of ignition more likely to be present in mills. The results of these tests with several different materials are shown in Table VIII.

In conducting these experiments the dust cloud was injected as soon as possible after the source of ignition had been placed in the lower end of the gallery. Occasionally an explosion occurred immediately after the dust was injected, but usually there was a lapse of one to four seconds between the injection of the dust and the explosion. Apparently it took that length of time for an explosive mixture to form around the flame or arc. It is of interest to note the results and to compare them with those obtained in the horizontal gallery. For instance, varying degrees of propagation were obtained with coal dust, and no ignition could be obtained with a mixture of 90 per cent coal dust and 10 per cent shale dust, while in the horizontal gallery propagation was obtained with a mixture of 60 per cent coal and 40 per cent shale. This may have been due to a greater concentration of the shale dust in the lower end of the gallery on account of its higher specific gravity.

A candle flame gave a good ignition of a 40 per cent sulphur and 60 per cent coal mixture while only a weak propagation was obtained in the ignition of the same mixture with an electric arc. An ignition around the candle flame but no propagation was obtained with a mixture of 30 per cent sulphur and 70 per cent shale, while in the horizontal gallery a 20 per cent sulphur and 80 per cent shale mixture behaved as did pure coal dust. Also some dusts, as barley, pea and alfalfa, were not ignited by the candle flame but were easily ignited in the horizontal gallery.

These results should not be taken to mean that some dusts cannot be ignited by a candle flame, but simply that they will not be ignited by it under all conditions. Under other circumstances they have been easily ignited by simply shaking them out of a cloth as a cloud over the flame. The chief reason they ignited in the horizontal and not in the vertical gallery was probably the greater heat of the igniting source and its more sudden application.

When two samples, supposedly of the same dust, or of a material as uniform as a starch—corn, rice or wheat, for instance—give different results, there must be some reason for it outside of composition. A number of factors affect the inflammability of a dust, controlling not only the ease with which it may be ignited, but also the rapidity with which an explosion once initiated will propagate through the cloud. Among these are size of the dust particles, moisture content, ash, volatile material in the dust, and ease of oxidation.

TABLE VIII.

INFLAMMABILITY OF DUSTS AS TESTED IN VERTICAL GALLERY.

Test No.	Material.(1)	Ignition.	Flame.	Remarks.
3	Coal dust	Sterno lamp on floor.	Out end	—
17	Coal dust	Arc	Out end	—
26	Coal dust	Arc	Weak ignition	—
13	Coal dust	Candle on floor	Out end	—
22	80% coal, 20% shale	Arc	No ignition	—
25	90% coal, 10% shale	Arc	No ignition	—
38	Coal dust, 200-mesh.	Arc	Flame	Arc allowed to heat carbons.
1	Starch	Sterno lamp on floor.	Out end	—
9	Starch	Candle on floor	Out end	—
16	Starch	Arc	Out end	—
23	50% starch, 50% shale	Arc	Flame out	—
27	40% starch, 60% shale	Arc	Out end	—
30	30% starch, 70% shale	Arc	No ignition	—
51	35% starch, 65% shale	Arc	Flame just through.	—
50	30% starch, 70% shale	Candle	No ignition	—
48	35% starch, 65% shale	Candle	Out end	—
6	Potato starch 28-A.	Sterno lamp on floor.	Out end	—
104	75% potato starch 28-A., 25% shale	Candle	No ignition	—
41	Potato starch 16-A.	Arc	Flame	—
101	50% potato starch 16-A., 50% shale	Arc	Just ignited	No propagation.
99	40% potato starch 16-A., 60% shale	Candle	Ignited at candle	No propagation.
2	Flour	Sterno lamp on floor.	Out end	—
8	Flour	Candle on floor	Out end	—
15	Flour	Arc	Out end	—
28	60% flour, 40% shale	Arc	Out end	—
31	40% flour, 60% shale	Arc	No ignition	—
5	Rice flour	Sterno lamp on floor.	Out end	—
47	50% rice flour, 50% shale	Arc	No ignition	—
52	60% rice flour, 40% shale	Arc	Out end	—
53	55% rice flour, 45% shale	Arc	Out end	—
55	55% rice flour, 45% shale (See Exp. 47).	Candle	Out end	—

TABLE VIII — *Continued*

Test No.	Material.	Ignition.	Flame.	Remarks.
54	60% rice flour.... 40% shale.......	Candle...........	Out end.........	—
75	Rice dust from mill top of reel.	Candle...........	Good ignition.....	—
76	Rice dust from mill top of reel.	Arc..............	No ignition.......	—
56	Cyclone dust from rough rice receiver.	Arc..............	No ignition.......	—
57	Cyclone dust from rough rice receiver.	Candle...........	No ignition.......	—
4	Sulphur...........	Sterno lamp on floor.	Out end.........	—
11	Sulphur...........	Candle on floor.....	Out end.........	Violent.
40	Sulphur...........	Arc..............	Flame...........	Ignited immediately on injection.
105	40% sulphur..... 60% shale.......	Candle...........	Good ignition.....	—
107	40% sulphur..... 60% shale.......	Arc..............	Flame just through.	—
106	30% sulphur..... 70% shale.......	Candle...........	Ignited at flame...	No propagation.
10	Alfalfa............	Candle on floor.....	No ignition.......	—
7	Alfalfa 200-mesh...	Sterno lamp on floor.	No ignition.......	—
95	Alfalfa 200-mesh...	Candle...........	No ignition.......	—
33	90% alfalfa No. 2 200-mesh. 10% shale.........	Arc..............	No ignition.......	—
64	Wheat dust caught near elevator leg.	Candle...........	No ignition.......	—
65	Wheat dust from around 1st floor leg.	Candle...........	No ignition.......	—
67	Wheat dust from milling separator.	Candle...........	No ignition.......	—
69	Corn elevator dust..	Candle...........	No ignition.......	—
39	Corn elevator dust No. 9.	Arc..............	No ignition.......	—
46	Corn elevator dust No. 9.	Sterno flame.......	Ignited at flame...	Did not propagate.
70	Corn dust from around grate.	Candle...........	No ignition.......	—
60	Pea dust, pure.....	Candle...........	No ignition.......	—
59	75% pea dust.... 25% shale.......	Candle...........	No ignition.......	—
61	40% tapioca dust. 60% shale.......	Candle...........	Flame just through.	—
62	40% tapioca dust. 60% shale.......	Arc..............	Ignition at arc....	No propagation.
63	Flax dust.........	Candle...........	Flame just through.	—
68	Barley dust........	Candle...........	No ignition.......	—
77	Flour dust, rolls and purifiers.	Candle...........	Good ignition.....	—
78	50% flour dust, etc. (No. 103). 50% shale.......	Candle...........	Good ignition.....	—

TABLE VIII — *Continued*

Test No.	Material.	Ignition.	Flame.	Remarks.
81	50% flour dust, etc. (No. 103). 50% shale.......	Arc..............	Weak ignition.....	—
80	40% flour dust, rolls and purifiers No. 103. 60% shale.......	Candle...........	No ignition.......	—
82	Sample No. 1 dusts from receiving scourer.	Candle...........	Big volume flame..	—
83	Sample No. 1 dusts from receiving scourer.	Arc..............	Big volume flame..	—
84	50% reduction middlings. 50% shale.......	Candle...........	Out end.........	—
85	40% reduction middlings. 60% shale.......	Candle...........	Slow flame out....	—
86	40% reduction middlings. 60% shale.......	Arc..............	Ignition at arc....	No propagation.
89	Mixture, oats, wheat and barley.	Candle...........	No ignition.......	—

(1) A loading of 4 grams of material in each test.

Volatile Matter. Most investigators who have studied the question of coal-dust explosions have expressed the belief that the inflammability of the dusts is related to, if not directly dependent upon, the amount of volatile matter in the coal. This seemed to be borne out by tests and by the fact that most dusts of low volatile content were either only very slightly explosive or could not be ignited under ordinary conditions. For a long time it was thought that an explosion could not occur without the presence of gas. Consequently, when an explosion did occur where no gas was expected or known to be present the natural conclusion was that a gas must have been given off, and that it was this gas which exploded or at least aided in the propagation of the explosion. In 1876 Galloway stated that if coal dust and air did not form an inflammable mixture a small addition of fire damp, which would not be inflammable alone, would become inflammable when coal dust was added. Bedson and Widdas[1] call attention to the effect of the volatile matter and state that the amount of it in the coal is an indication of the inflammability and explosive character of the coal. As a result of a series of experiments at the French Experiment Station it was concluded that the order of inflammability is the same as that of the content of volatile matter

[1] Trans. Inst. Min. Eng., 1908, vol. 34, pp. 91-97.

PLATE II.—Photograph of Vertical Gallery.

in the coal. The British authorities, however, did not feel that this was the controlling factor, and Wheeler[1] stated that the inflammability is dependent upon the amount of paraffins distilled from the coal. He found that this was proportional to the amount of material extracted from the dust by pyridine. The Bureau of Mines,[2] following their first tests, stated: "It has been pretty well demonstrated by these experiments that the order of inflammability of a coal dust is a function of the amount and character of the volatile matter which is expelled." As a result of later tests,[3] it was stated that no definite relation between inflammability and volatile matter content is shown, but that there is a decided tendency for the inflammability to increase as the percentage of volatile matter increases.

TABLE IX.

RELATION OF COMPOSITION TO INFLAMMABILITY.

Sample No.	Kind of dust.	Inflammability pressure.	Volatile matter.	Fixed carbon.	Ash.	Water.	B. t. u.
		Pounds per square inch.	Per cent	Per cent	Per cent.	Per cent.	
61	Yellow corn dust from first break in dry milling.	15.2	74.18	15.125	0.475	10.22	6804
35	Wheat elevator, side wall...	13.0	62.88	14.45	16.21	6.46	7214
43	Oat and corn dust, top of elevator.	12.4	63.08	16.18	12.84	7.90	6628
57	Oat dust from ground oat hulls.	12.3	69.51	18.29	4.86	7.34	7717
103	Wheat flour dust rolls and purifiers.	10.5	68.52	21.18	0.75	9.55	7259
97	Reduction middlings.......	9.4	68.47	21.38	0.47	9.68	7231
33	Wheat flour from packing room.	9.3	65.66	24.66	0.56	9.12	7213

While it is evident that the percentage of volatile matter is an indication of the inflammability of a coal dust this is not an important factor in controlling the inflammability of dusts other than coal. This is shown in Table IX, which gives the results of approximate analyses made upon some of the dusts given in Table V. It will be noted that the most inflammable dust does have the highest percentage of volatile matter, and that the one with the lowest volatile content is next to the most inflammable. In fact, the percentage of volatile matter and the relative inflammability do not show any relation whatsoever. This might have been expected from earlier discussion in this chapter for it was shown that most of the volatile matter given off by vegetable material and carbohydrates is not inflammable. This is further indicated by the results in Table X.

[1] J. Chem. Soc., vol. 99, p. 649; vol. 103, p. 1704; vol. 103, p. 1715.
[2] U. S. Bureau of Mines, Bull. 20.
[3] U. S. Bureau of Mines, Bull. 102, p. 67; Technical Paper 141, p. 24.

TABLE X.

VOLATILE MATTER PRODUCED BY COMPLETE DISTILLATION OF CELLULOSE AND STARCH TO 500° C. AND OF TWO COALS TO 450° C.

	Dry material, to 500° C.		Air-dried material, to 450° C.	
	Cellulose.[1]	Starch.[1]	Pittsburgh coal.	Wyoming coal.
Total volatile (per cent)	67.1	71.4	22.00	35.45
Water (per cent):				
Free	—	—	.93	5.98
Combined	31.7	29.7	4.30	12.64
Acetic acid (per cent)	3.3	5.3	—	—
Aldehydes and ketones (per cent)	5.9	6.8	—	—
Carbon dioxide (per cent by weight)	11.3	13.1	.31	3.78
Carbon monoxide (per cent by weight)	4.8	7.6	.21	1.60
Tar (per cent by weight)	3.3	2.7	12.76	8.17
Inflammable gases (other than CO)	1.3	2.0	3.16	2.80
Gas (as cc. per 100 grams):				
Carbon dioxide	6363	7365	174	2128
Carbon monoxide	4268	6821	187	1426
Unsaturated hydrocarbons	213	347	352	394
Methane	1056	1273	1953	1778
Ethane, etc.[2]	281	593	1147	869
Hydrogen	247	370	653	1129
Total gas	12,428	16,769	4.466	7,724
Inflammable gases, as per cent (by volume) of total gases.	48.8[3]	56.1[3]	96.1[3]	72.6[3]
Inflammable material, as per cent (by weight) of total volatile.[4]	15.4	19.0	73.3	35.4

[1] Bautling, J. für Gasbeleuchtung, vol. 57, pp. 32-55.
[2] Lower hydrocarbons figured as ethane.
[3] 70-75 per cent of this is CO.
[4] Aldehydes and ketones omitted.

While it is evident that cellulose and starch decompose by heat much more easily than does coal, the vapors and gases formed in the early decomposition are 80-90 per cent non-combustible. Furthermore, while the quantity of combustible gases produced by heating cellulose and starch is greater than that produced from coal, these gases are largely made up of carbon monoxide, which is a gas of a comparatively low degree of inflammability. The more highly inflammable gases, as methane, ethane and hydrogen, are produced (at 500° C.) probably in as great, if not greater, quantities from the Pittsburgh coal as from cellulose and starch. This would indicate that it is necessary to look to some other cause than the capability of producing inflammable volatile matter if the high degree of inflammability of cellulose and starch, and probably all other dusts, is to be explained.

Ash.—It would be reasonable to expect that a dust with a high ash content would be less inflammable than one with a low percentage of

ash or inert material in its composition. Authorities differ on this point, however. One[1] says that the greater the content of inert material, as ash and moisture, the lower will be the inflammability, while another[2] states that the ash content of the coal, within ordinary limits, does not appear to affect the explosibility of the coal dust.

A brief study of the results shown in Tables III, IV, IX and XI, will give some idea of the effect of ash in ordinary amounts as found in the dusts. In Table III it will be noticed that the most inflammable of the dusts, other than coal, has an ash content of 1.59 per cent, while the least inflammable has only 0.43 per cent, and some between have as high as 7 per cent of ash. In the coal dusts it is true that one of the most inflammable has the lowest ash content, 3.57 per cent, but the next one in degree of inflammability has nearly the highest percentage of ash of any, except one which has 16.78 per cent and still is more inflammable than some others. It will also be noticed that some of the coal dusts are more inflammable than some of the other dusts which have a lower ash content. A glance at Table IV will show the same lack of relation between the percentage of ash and the relative inflammability. In Table IX it will be seen that the most inflammable dust has practically the lowest ash content, 0.475 per cent, while the next in order of inflammability has the highest amount of ash of any of these dusts, 16.21 per cent.

In its large-scale tests the Bureau of Mines establishes a relation between the dusts by determining the amount of shale dust which it is necessary to add to make the propagation of an explosion impossible. In developing the laboratory method for testing dusts to predict their behavior in the large-scale experiments an exhaustive series of tests was made[3]. The addition of the shale dust affects the inflammability of the coal dusts differently, apparently depending upon the volatile content. After the addition of the same amount of shale dust to each of the coals tested, that dust which had the highest volatile content was the least affected. With the addition of a small amount of shale dust the inflammability was not decreased materially, but it decreased gradually with the increase of the inert dust. However, in some cases it was necessary to add over 50 per cent of the inert dust before the dust failed to propagate an explosion. This means that there must be over that percentage of ash in this type of dust to have it non-flammable.

In the tests described above, results of which are given in Table VII, it will be observed that in some cases it was necessary to mix from 70-80 per cent of shale with the dust before the mixture was rendered non-flammable and non-explosive.

The effect of the high percentage of ash naturally occurring in the dust is indicated by the results shown in Table *XI*, which gives the ash content of a few of the dusts appearing in Table *V*. It will be seen

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[1] U. S. Bureau of Mines Bull. 102, p. 66.
[2] U. S. Bureau of Mines Bull. 20, p. 101.
[3] U. S. Bureau of Mines Technical Paper 141.

that a dust with as high as 57 per cent ash can be quite inflammable and that one with 48 per cent ash may not show any inflammability. The results with rice dust are worthy of note since they are about as clear a demonstration of decrease of inflammability with increase of ash content as will be found. Though discrepancies appear, still there is at least an indication of the effect of high ash content. While the amount of ash must have some effect upon the inflammability of the dust, especially if it is very high, it does not seem to have any marked effect in the quantities ordinarily present. Consequently, it is necessary to look further for those things which affect the inflammability of the dust to a greater degree.

TABLE XI.

EFFECT OF ASH ON INFLAMMABILITY OF RICE DUSTS.

Sample No.	Kind of dust.	Explosion Pressure. Pounds per square inch.	Ash. Per cent.
54A	Rice polish dust from polisher	10.1	8.06
83A	Rice polish dust from collector around polisher.	9.3	7.05
85A	Rice bran dust	8.7	21.49
55A	Rice dust from cleaning	7.9	29.33
82A	Rice dust	7.1	35.52
84A	Rice dust from shaker	4.8	53.40
53A	Rice dust from bins above cyclone from receiving aspirator.	4.8	56.77
56A	Rice dust from clippers	3.9	50.40
52A	Cyclone dust from rough rice receiving aspirator.	0.0	47.66

Size of particles. The rate at which any substance will be oxidized or will burn is dependent upon the surface exposed to the oxygen of the air. The greater the area exposed the more rapid will be the oxidation and the finer the dust the greater the surface exposed if the dust is thoroughly mixed with the air, as in a cloud. It would be expected, therefore, that a fine dust would burn more rapidly than a dust which had less surface per unit weight. This is only another way of saying that a flame would propagate more rapidly through a cloud of fine dust than through a cloud of coarse dust. It would also be ignited more easily, and so the finer the dust the more inflammable it would be expected to be.

As a result of tests Vital[1] concluded that the intensity of an explosion is intimately connected with the character of the dust and becomes practically nil if the size of the particles is increased to an appreciable part of a millimeter. A little later Mallard and Le Chatelier[2] found that the

[1] Annales des Mines, 1875, ser. 7, vol. 7, p. 180.
[2] Annales des Mines, 1881, ser. 7, vol. 20, pp. 121-159.

more finely divided were the dusts, the more inflammable they became, and the smaller was the size of the flame necessary for their ignition. Yet in many previous tests these authors had thought that fineness of division was a secondary matter. Some coals were found inflammable regardless of the size of the particles. This fact is not opposed to the principle that the more finely divided the coals, the greater the inflammability, for the authors explain that the dusts used by them were not screened to a certain size, and that in all the samples a sufficient amount of the fine dust remained in suspension long enough to cause ignition on arrival at the source of heat. In this way the occurrence of fine dust in a sample, the average size of whose particles was large, would mask the effect that might be anticipated from the relatively large size of the particles. For instance, two samples of dust may be very different with respect to fineness when introduced into the apparatus but in the course of their passage to the flame, situated some distance away, the largest particles are deposited and only the smaller particles reach the flame, so that at this point both dust clouds are very similar as regards the size of the particles remaining in suspension.

The Bureau of Mines[1] made a series of tests in the gallery at Pittsburgh on the propagation of flame by different sizes of coarse coal dusts. These results are given in Table XII. The dusts were thrown into suspension and ignited by a blast of 1¼ to 2½ pounds of black powder. It will be noticed that 60-80-mesh dust propagated an explosion as did 40-60-mesh dust. While there was ignition with the 20-40-mesh dust, there was only partial propagation, but the indications were that with a still larger charge of powder, increasing the concussion and heat of the initial explosion, complete propagation would be produced. In a mine, still coarser sizes of dust might propagate the flame from very large shots, in view of the fact that smaller sizes would be present to sustain the flame.

In a report[2] of recent experiments conducted in Germany, as a result of two disastrous explosions in sugar refineries during the war, one conclusion reached is described as follows: "The finer the dust, the more easily it exploded. This fact is not difficult to explain. The finer the dust in a cloud, the larger the area of all dust particles in comparison to the content, and the more easily can a sudden vaporization of the dust be produced by contact with heat. The finer a dust the more readily it remains in the air. This increases the possibility of spreading quickly and easily a sudden ignition of the dust occurring at any particular point."

During the tests described (see Page 25 and Table V) uniform results were sometimes very difficult to obtain, using two samples of the same dust, even though only that portion of the dust which would pass a 200-mesh screen was used. This, it was thought, could be caused only by the presence of varying amounts of dust much finer than the maximum

[1] U. S. Bu. of Mines Bull. 20, pp. 43-45.

[2] Zeitschrift fur das Berg-Hutten-u-Salinenwesen, 1920, Abhandlungs-Heft-3, s. 100.

size which would pass through a 200-mesh screen. It was found that the Bureau of Standards had developed a method[1] and apparatus for making separations of very fine cement dust. Using air currents, it was possible to make separations much finer than could be made with sieves. This apparatus was used by the Bureau of Chemistry in an attempt to separate samples of other dusts which had been screened through a 200-mesh sieve. It was apparent that a slightly different type of apparatus was necessary. After a large number of experiments, the apparatus[2]

TABLE XII.

TESTS OF PROPAGATION OF FLAME BY DIFFERENT SIZES OF COARSE COAL DUST.

(All charges of explosive tamped with clay.)

No.	Weight of explosive used for ignition.	Dust used.*a*		Flame showed (indicating its length) at —		Result.	
	Pounds.	Weight Pounds.	Size Mesh.	Doors Nos.	Windows Nos.	Ignition.	Propagation.
1	1¼	10	20–40	(b)	1–4	No	No
2	1¼	20	20–40	(b)	1–5	No	No
3	1¼	10	40–60	—	1–3	No	No
4	1¼	20	40–60	—	1–3	No	No
5	1¼	10	60–80	2–4	1–5	Yes	No
6	1¼	20	60–80	2–6	1–14	Yes	Yes
7	1¼	10	80–100	2–7	1–14	Yes	Yes
8	1¼	17	60–80	2–14	1–14	Yes	Yes
9	1¼	14	60–80	3–7	1–14	Yes	Yes
10	2½	10	60–80	3–9	1–12	Yes	Yes
11	2½	10	60–80	2–11	1–14	Yes	Yes
12	2½	12	40–60	2–12	1–14	Yes	Yes
13	2½	15	20–40	2–5	1–8	Yes	Partial
14	2½	23	20–40	2–3	1–6	Yes	Partial

a Dust was placed on a horse in the first three sections, and on shelves in sections 3-6, except in test 13 and 14, in which dust was placed on shelves in sections 3-9 and 3-11, respectively.
b Edge of door 3.

NOTE: The gallery consists of 15 sections each 6 feet 8 inches long with a window on the observation side and a relief door on top in the middle of each section.

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[1] U. S. Bureau of Standards, Technical Paper No. 48.

[2] The apparatus consists of a funnel of special construction which is held up against a metal stack. The middle portion of the stack is 30 inches long and 6 inches in diameter. It has been drawn in at the bottom to avoid using so large a funnel. At the top the stack is drawn in to 3.5 inches diameter and has a 45-degree elbow on which a bag is placed to catch the dust which is carried up the stack.

To make the separations a known weight of dust is placed in the funnel, usually from 25 to 50 grams. It is then agitated by allowing air under one pound per square inch pressure to pass up through the funnel. The different separations are obtained by controlling the rate of flow of the air with orifice plates inserted between the funnel and the source of air pressure. In the finest separations a 1-mm. plate was used, while a 4-mm. plate had been used in the coarsest separations. By having a large variety of orifice plates as many and as fine separations can be made as desired. The size of the particles in each fraction is determined microscopically.

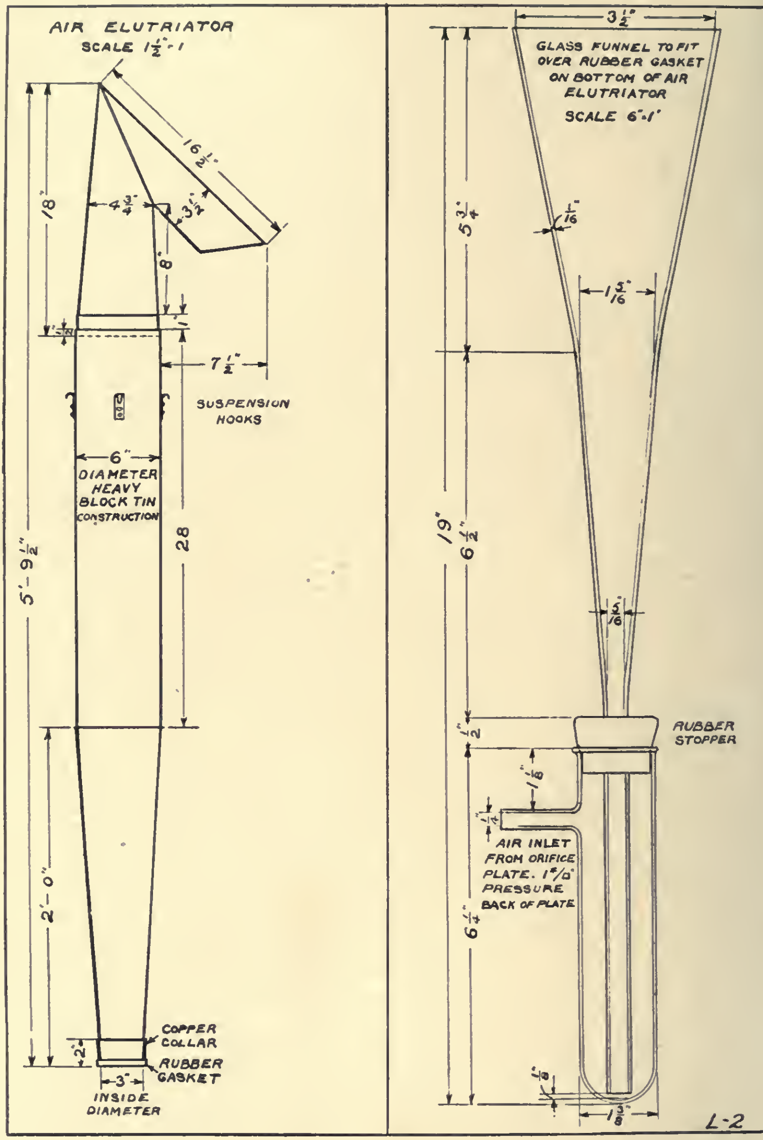

Fig. 10.
Air Elutriator.

shown in Figure 10 was developed. This made it possible to make as many and as fine separations of 200-mesh material as desired. Dust placed in the funnel at the lower end of the apparatus is agitated by air under pressure of 1 pound per square inch, orifice plates controlling the flow and, consequently, the separations. The more slowly the air moves, the smaller the particles that are carried over into the receiver. The size of these particles can then be measured with the aid of a microscope.

By means of this apparatus and method, separations were made of a large number of dusts, and the various fractions obtained were tested

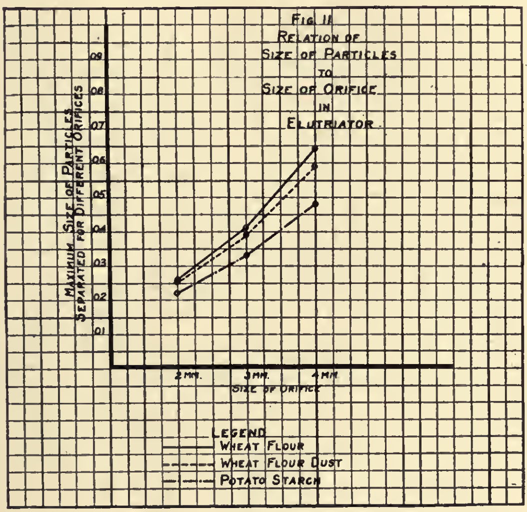

Fig. 11.
Curve Showing Maximum Size of Dust for Different Orifices.

to determine their relative inflammability. The results are given in Table XIII, and, for a clearer understanding, some of them are given in the form of curves in Figures 11 to 13. These curves give the maximum size of the particles in the fraction for different orifices; the amount of dust separated by the various orifices, and the inflammability of dust of varying size particles, with normal moisture content and free from moisture.

Even a casual glance at this table and the curves should be sufficient to indicate the great effect which the size of the particles has upon the inflammability of the dust. It is clearly shown that as the size of the particle decreases the relative inflammability increases, usually to a very marked degree. However, in some cases the pressure generated in the ignition of the smallest particles is less than that given by the fraction next larger. This is probably caused by the moisture in the sample, which causes the particles to agglomerate, so that when they are injected

into the apparatus they do not separate and act as individual particles, but rather as particles of larger dimensions. It will be noticed that this is not the case when the moisture has been removed from the dust. In every case (except Sample 42A—cocoa dust containing high oil content which causes agglomeration), when the dusts are dry their relative inflammability increases as the size of the particles decreases.

A study of some of the results in Table XIII from a slightly different angle will throw further light on the effect of size of particles upon the inflammability of dust and show that while this is very important it is not the only factor to be considered. In Table XIV the results of the inflammability tests upon the various fractions have been arranged according to the maximum sized particles obtained in separating the dusts with a certain fixed rate of flow of air in the separator.

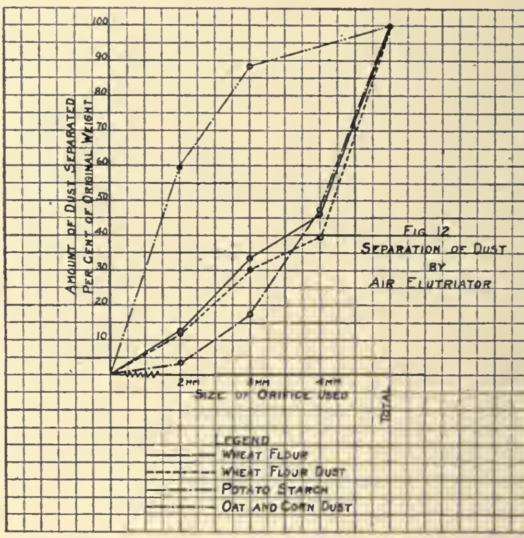

Fig. 12.
Curve Showing Amount of Dust for Different Orifices.

A brief comparison of the size of particles and the inflammability of the fractions of the various dusts, separated by any one rate of flow of air, will show that, in general, the relative inflammability of different dusts is not entirely controlled by the size of particles. For instance, of the samples obtained with a 2.0-mm. orifice, the most inflammable is the one which has the largest particles and which does not contain any particles much smaller than the coarsest present in the finest sample, all of these having been removed by using a 1.5 mm. orifice. It is true that the finest is the next in order of inflammability, but the one which stands third in inflammability is fifth in order of fineness. A similar condition exists in the other groups of fractions in the table. For example, it will be noticed that the finest sample in those separated by

the 3-mm. orifice is fourth in inflammability, and the highest in inflammability in the samples separated by the use of the 4-mm. orifice is fourth in size of particles. These differences cannot be explained by the presence of large proportions of particles which are much smaller than the maximum sized particles given. The only indication of the amount of such fine materials would be the percentage of the original sample in each fraction. If the first fraction is very large and the second considerably smaller it might be expected that the first contained a high percentage of material considerably finer than the maximum indicated, while a small first fraction and a large second would indicate that there was

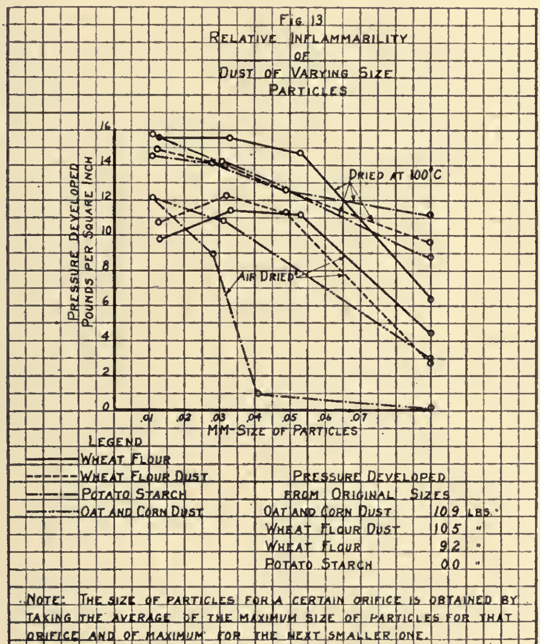

Fig. 13.
Curve Showing Inflammability for Different Sizes of Dust.

not a high percentage of smaller particles in the first fraction. The 2.0 mm. fraction from Sample 37 contains 59.52 per cent of the original and the next fraction, 29.07 per cent of the total. This indicates a high per cent of material smaller than .02158 mm. which may be a reason for its high inflammability. Still, the next fraction does not contain any of these very small particles, and the extreme variations in size are only 0.01857 mm., yet this fraction gives an inflammability of 14.2 as against 15.7 for the finer fraction. Also, the finer fraction of Sample 50A, which contains nearly 40 per cent of the original, is less inflammable

TABLE XIII.

AIR SEPARATIONS.

Sample No.	Kind of dust.	Relative inflammability of sample before separation. 200-mesh material.	Flow of air at 1-pound pressure controlled by: 2.0 mm. orifice.				3.0 mm. orifice.				4.0 mm. orifice.				Residue. Maximum size particles just passing 200-mesh screens.		
		Pressure in pounds per square inch	Maximum size mm.	Per cent separated.	Relative inflammability pounds per square inch. Air dry.	Dried at 100° C.	Maximum size mm.	Per cent separated.	Relative inflammability pounds per square inch. Air dry.	Dried at 100° C.	Maximum size mm.	Per cent separated.	Relative inflammability pounds per square inch. Air dry.	Dried at 100° C.	Per cent.	Inflammability pounds per square inch. Air dry.	Dried at 100° C.
28A	Potato starch........	0.0	.02249	3.64	12.1	14.5	.03348	13.80	8.9	14.0	.04852	29.92	0.9	12.8	52.64	0.1	11.1
35	Wheat elevator dust..	8.0	.02407	10.0	37.23		.03777	30.48	10.1		.05753	19.26	5.9		13.03	2.0	
	Wheat flour.........	9.2	.02643	12.76	9.8	15.5	.04108	20.68	11.4	15.5	.06405	12.88	11.1	14.6	53.68	4.4	6.3
42A	Cocoa powder from cocoa cooling room.	9.9	.02738	8.89	4.2	7.3	.04238	45.88	9.8	11.3	.05682	14.60	10.2	10.7	30.63	8.6	10.2
*24A	Corn dust from unloading station.	10.4	.02531	33.17	12.5		.04687	31.56	10.7						22.07	4.2	
103	Wheat flour dust—rolls and purifiers.	10.5	.02539	12.64	10.7	14.9	.03929	17.52	12.2	13.9	.05917	9.12	11.2	12.5	60.72	2.7	9.6
50A	Malt dust from dust collector.	10.6	.02607	39.76	10.7	12.2	.04672	28.72	10.5	12.6	.08137	11.40	8.9	10.4	20.12	0.6	
X13C	Pittsburgh standard coal dust.	10.7	.02898	37.08	12.6	12.5	.04896	28.28	10.9	10.3	.07185	19.96	7.2	7.1	14.68	3.9	3.9
37	Oat and corn dust from unloading station.	10.9	.02158	59.52	12.1	15.7	.04015	29.07	10.8	14.2					11.41	2.9	8.7
*36A	Wood dust from chipper room.	11.8	.03251	18.13	11.8	18.1	.04975	53.36	11.2	15.5					14.27	9.3	10.6

* On account of the large amount of very fine material in these two samples, separations were made, using a 1.5 mm. orifice to control the flow of air; 14.24% of the wood dust from the chipper room was so separated, with maximum sized particles of .02135 mm. diam., which when ignited gave a pressure of 10.4 lbs., and after drying a pressure of 18.3 lbs., while 13.20% of the corn dust was so separated, with maximum sized particles of .01811 mm. diam., which when ignited gave a pressure of 12,6 lbs,

TABLE XIV.

EFFECT OF SIZE ON INFLAMMABILITY.

Sample No.	Kind of dust.	Size of orifice controlling air.	Maximum size particles.	Per cent of original sample.	Relative inflammability
		mm.	mm.		Pressure Pounds per square inch
36A	Wood dust from chipper room.	1.5	.02134	14.24	18.3
37	Oat and corn dust............	2.0	.02158	59.52	15.7
28A	Potato starch.................	2.0	.02249	3.64	14.5
103	Wheat flour dust, roll and purifiers.	2.0	.02539	12.64	14.9
50A	Malt dust from collecting system.	2.0	.02606	39.76	12.2
	Wheat flour.................	2.0	.02643	12.76	15.5
42A	Cocoa dust..................	2.0	.02738	8.89	7.3
X13C	Pittsburgh coal dust..........	2.0	.02898	37.08	12.5
36A	Wood dust from chipper room.	2.0	.03251	18.13	18.1
28A	Potato starch................	3.0	.03348	13.80	14.0
103	Wheat flour dust.............	3.0	.03928	17.52	13.9
37	Oat and corn dust............	3.0	.04015	29.07	14.2
	Wheat flour.................	3.0	.04108	20.68	15.5
42A	Cocoa dust..................	3.0	.04238	45.88	11.3
50A	Malt dust...................	3.0	.04672	28.72	12.6
X13C	Coal dust...................	3.0	.04896	28.28	10.3
36A	Wood dust..................	3.0	.04975	53.36	15.5
28A	Potato starch................	4.0	.04851	29.92	12.8
42A	Cocoa dust..................	4.0	.05682	14.60	10.7
103	Wheat flour dust.............	4.0	.05917	9.12	12.5
	Wheat flour.................	4.0	.06405	12.88	14.6
X13C	Coal dust...................	4.0	.07184	19.96	7.1
50A	Malt dust...................	4.0	.08137	11.40	10.4
37	Oat and corn dust............	Residue after 4 mm. orifice.	About .1100	11.41	8.7
28A	Potato starch................	Residue after 4 mm. orifice.	.1100	52.64	11.1
103	Wheat flour dust.............	Residue after 4 mm. orifice.	.1100	60.72	9.6
	Wheat flour.................	Residue after 4 mm. orifice.	.1100	53.68	6.3
42A	Cocoa dust..................	Residue after 4 mm. orifice.	.1100	30.63	10.2
X13C	Coal dust...................	Residue after 4 mm. orifice.	.1100	14.68	3.9
36A	Wood dust..................	Residue after 4 mm. orifice.	.1100	14.27	10.6

than the next fraction which contains about 29 per cent of the original, with particles which vary in size by 0.02066 mm.

In Table XV the materials are arranged according to the inflammability of the finest fraction. When compared to the other fractions it can be seen the same order does not exist. So, while it is seen that the size of the particles of a particular dust is an important factor and to a large extent does control its inflammability, there seems to be some

other element to be taken into consideration. The shape of the particles is important also as it affects materially the amount of surface exposed to the oxygen of the air. Undoubtedly this explains some of the differences in the results shown, but this point is difficult to determine without a detailed microscopic study of the various samples.

It is very probable that the size of the particles of a dust has more to do with its relative inflammability than any other one thing, especially when dusts of similar materials are considered. In fact it may almost be said, after a study of these results, that a determination of the size, as well as the shape, of the particles will give an excellent indication of the relative inflammability of a particular type of dust. Of the factors which have an important bearing upon the inflammability of dust this seems to be one of the most important, if not the most important.

Moisture content.—Another factor which influences the inflammability of dust is its moisture content. The Bureau of Mines in discussing the effect of moisture[1] makes the following statement: "Moisture contained

TABLE XV.

INFLAMMABILITY OF VARIOUS SIZED FRACTIONS.

Sample No.	Kind of dust.	Inflammability of fractions by orifice.			
		2.0 mm.	3.0 mm.	4.0 mm.	Residue
36A	Wood dust	18.1	15.5	—	10.6
37	Oat and corn dust	15.7	14.2	—	8.7
	Wheat flour	15.5	15.5	14.6	6.3
103	Wheat flour dust	14.9	13.9	12.5	9.6
28A	Potato starch	14.5	14.0	12.8	11.1
X13C	Coal dust	12.5	10.3	7.1	3.9
50A	Malt dust	12.2	12.6	10.4	—
42A	Cocoa dust	7.3	11.3	10.7	10.2

or carried in coal dust is probably converted to steam before gas is evolved from the dust particles, and if enough moisture is present the absorption of heat in this way may prevent sufficient heat from being imparted to adjacent dust particles to evolve the volatile gases and raise them to the ignition point. Furthermore, if the moisture in or surrounding each particle of dust is sufficient in quantity, the vapor therefrom will dilute evolving gases or else tend to surround them with an incombustible envelope and so prevent the immediate ignition of the combustible matter necessary for propagation." In referring to the use of exhaust steam as a means of preventing explosions in mines the Bureau of Mines[2] also states: "Exhaust steam is used to prevent coal-dust explosions on the theory that wet coal is more difficult to ignite than dry coal; also that a flame propagating through moist air suffers a greater temperature loss than one propagating through dry air.

[1] U. S. Bu. of Mines Bull. 20, p. 100.
[2] U. S. Bu. of Mines Bull. 20, p. 166.

"To make coal dust absolutely and theoretically inert as a combustible —that is, to make a mixture of such composition that it would not ignite or consume from heat of its own generation—would require six or seven times its weight of water. This quantity of water is so large, causing, in fact, a condition practically equivalent to submergence, that its use is impossible."

The results shown in Table XIII and in Figure 13 give some idea of the effect of moisture upon the inflammability of dust. It will be noticed that a dry dust ignites much more readily than a dust with normal moisture content. The most striking illustration of this is shown where the residue of the separation of potato-starch dust was not ignited in the tests upon the ordinary air-dried material, but when the moisture was removed it gave a very high inflammability. This effect is also shown very well by wheat flour dusts. Other things being equal, the drier a dust the more inflammable it is, or the more moisture it contains the less inflammable it is. That moisture causes agglomeration has been noted, but it is believed its real effect is to absorb some of the heat of ignition or combustion and thereby lower the temperature. Not until the moisture content is sufficiently high to absorb from the source of ignition an amount of heat which will lower it to a point below the ignition temperature of the dust will its presence prevent an explosion. An increased moisture content, consequently, raises the ignition temperature of the dust and so decreases its inflammability, that is, its ease of ignition.

An idea seems to exist that humidification of a mill would prevent explosions. It has prevented fires in picker rooms of cotton mills, but here a different condition exists, one which will be discussed in a later chapter. Humidifying the atmosphere of a mill would tend to increase the moisture content of the dust over what it is in normal air and so raise the ignition temperature slightly, but the trouble and expense would not be justified by the benefits gained. However, the ordinary sources of ignition would still ignite the dust, and an explosion once started would be easily propagated. The effect of moisture is well explained by Bedson and Widdas,[1] when they state that in order to prevent the ignition of an inflammable dust it must be made so damp that it cannot be blown into the air as a cloud by a jet of air, and that an increase of moisture tends to raise the temperature of inflammation. The amount of moisture which must be present to raise the temperature of ignition or inflammation to the point that the dust will not ignite under ordinary conditions varies with different dusts. For instance, it was noticed that the sample of potato starch, Figure 13, could not be ignited under the conditions of the tests at 1200° C. when it contained only an ordinary amount of moisture, probably not over 10-12 per cent, and yet wheat-smut dust has been easily ignited[2] when it contained as much as 35 per cent of moisture.

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[1] Trans. Inst. Min. Eng., 1908, vol. 34, pp. 91-97.

[2] State College of Washington, Agricultural Experiment Station Bulletin 117, p. 11.

When a dust is not too wet to be thrown into suspension as a cloud, or as long as a cloud of it can be formed, it is not too moist to explode. However, moisture does have a marked effect upon the inflammability of the dust, an increase of moisture causing a decrease of inflammability.

Ease of oxidation.—It has been stated that the inflammability of a dust is the ease with which it will ignite and propagate an explosion. It may likewise be said that it is the ease with which a dust can be oxidized. The volatile content of the dust, its percentage of incombustible matter or ash, the size and shape of the particles, and the moisture content of the dust all have an important bearing upon this ease of ignition. Probably the size and shape of the particles have the greatest effect because they control the surface which is exposed to the action of the oxygen of the air, and so to a large degree control the rate and ease of oxidation. In referring to the effect of volatile matter on the inflammability of coal dusts, Mallard and Le Chatelier[1] express the opinion that the proportion of volatile matter is not the only cause of the inflammability of coal dust, but that those volatile constituents which have already been partially oxidized would be expected to be more inflammable than those same substances unoxidized, just as alcohol vapor is more inflammable than vapors of petroleum. This is only another way of expressing the idea that the chemical composition of dust has an effect upon its inflammability. Doubtless this is very true, for certainly substances of different chemical composition would not be inflamed with the same ease. For instance, natural-gas gasoline is much more inflammable than low-test gasoline although there is the same percentage of carbon and hydrogen in each, the difference being simply in the way they are combined in the molecules. Ether, an oxidized hydrocarbon, is more inflammable than either of them.

If the statement of Mallard and Le Chatelier, that the partially oxidized products are more inflammable than the unoxidized, is true, it may explain the fact that the starches, for instance, as also most of the dusts given in Table V, are more inflammable than coal dust. Most of these contain some starch or cellulose, which is of a similar composition. But it would be difficult to state positively that the opinion of Mallard and Le Chatelier is true, for, so far as known to the authors, there is no experimental evidence with which to substantiate its truth or falsity except possibly the fact that dust containing starch or cellulose or similar compounds in appreciable quantities seems to be more inflammable than coal and similar dusts.

Under proper conditions all substances which are not completely oxidized will burn, that is, will combine with the oxygen of the air. For example, iron will burn, or rust, but slowly at ordinary temperatures, but iron filings will burn brilliantly when dropped into a flame. Then, too, iron in a finer state of division, as iron reduced by hydrogen, can be ignited[2] by the flame of a match. In a still finer state of subdivision,

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[1] Annales des mines, 1882, ser. 7, vol. 20, pp. 5-98.

[2] Scientific American Supplement, May 25, 1878, vol. 5, No. 12, p. 1985.

obtained by the decomposition of iron oxalate by heat, iron is spontaneously inflammable when poured through air. Iron filings oxidize slowly at ordinary temperatures but do so very rapidly at high temperatures. That the rate of oxidation increases with the increase of temperature is generally true of all oxidation. Therefore, the higher the temperature of the igniting source, the more heat available for ignition, the more rapid will be the burning, and, in the case of a dust, the more violent will be the explosion. Mallard and Le Chatelier express this in stating that by increasing the size of the flame above a certain minimum the rapidity of inflammation is increased and for a certain volume becomes practically instantaneous and nothing is gained by increasing the size of the flame beyond this volume.

There is a maximum amount of heat in the case of all dusts which will give the maximum explosion obtainable. There is also a minimum temperature and amount of heat which must be present to ignite the dusts. It is very probable that the variations in this minimum for the different dusts is greater than the variations in the maximum amount of heat necessary to obtain the greatest explosive effect. The lower this temperature may be to obtain ignition, the more inflammable is the dust. In other words, the lower the temperature which must exist before rapid oxidation or the oxidation of burning begins the more inflammable the dust. This may be put in still another way by saying that the more easily a dust is oxidized the more inflammable it is.

Of all the various factors discussed above—volatile matter, ash, size and shape of particles, moisture content, chemical composition and ease of oxidation—and their effect upon the inflammability of dusts, it cannot be said that any one of them is the greatest factor. But where any one particular dust is considered the size of the particles seems to have the greatest effect upon the inflammability of that dust, and where various dusts are considered, size and shape of particles being the same, the ease of oxidation of the dust is the controlling factor.

CHAPTER II.

INDUSTRIES PRODUCING DUST AND THEIR EXTENT.

The subject of dust explosions has become one of real interest because of the large number which have occurred, entailing loss of life and property. But when the extent of the industries involved and the number of employees subject to this hazard are considered, it will be appreciated that it should become of even greater interest and study. Some idea of the number of employees and the value of the property—exclusive of coal mining, thresher operation, etc.—may be obtained from the data in Table XVI, which has been compiled from statistics of the Bureau of the Census, the Department of Labor, and the U. S. Grain Corporation.

In the operation of practically every industrial plant more or less dust is produced. This is especially true of the industries listed in Table XVI and of all of those handling fine materials or even coarser products which may be subject to abrasion in handling or manufacturing processes. In the older plants considerable dust was produced by the more or less imperfect methods of manufacture. If a plant had dust collecting equipment, it was inefficient and the machinery allowed the dust to get into the mill. But comparatively, these older plants on account of the slower moving machinery and smaller buildings, did not have anywhere near the possibilities for dust production and distribution which modern mills have with their many rapidly moving machines and with buildings constructed for maximum production. The great number of open pulleys and belts tends to create air currents and to distribute dust throughout the plant.

Though there are many exceptions, the methods used in all plants making a finer product from a comparatively coarse raw material are very similar—from the handling of the raw or partly finished material to the cleaning, pulverizing, separation, storing and packing. If the raw material is received and handled in bags or containers, the amount of dust created is usually not very great, but as this method is expensive and inefficient, the more dusty one of handling in bulk is adopted or retained. This method must be resorted to as soon as any manufacturing process is started, so from there on through most, if not all of the processes, dust is produced.

TABLE XVI.

NUMBER OF EMPLOYEES AND VALUE OF PROPERTY IN DUST-PRODUCING INDUSTRIES.

	No. of Establishments		Value of Products		Wage Earners (a)	
	1919	1914	1919	1914	1919	1914
Aluminum manufactures	84	37	$69,474,000	$19,597,000	11,402	5,018
Chocolate and cocoa products not including confectionery	48	36	139,258,000	35,713,000	9,083	4,512
Coffee and spice roasting and grinding	794	696	304,740,000	150,749,000	10,540	8,959
Cooperage	1,100	1,259	88,267,000	50,017,000	19,662	26,768
Cork, cutting	52	62	16,282,000	7,875,000	3,545	17,816
Fertilizers	599	784	278,610,000	153,196,000	26,296	38,332
Flour mill and grist mill products (d)	10,712	10,788	2,052,850,000	877,680,000	45,481	41,684
Fuel, manufactures	11	14	1,974,000	863,000	171	221
Glucose, starch	56	89	186,256,000	52,615,000	7,795	4,948
Lumber, planing mill products, not including planing mills connected with saw-mills	5,314	5,841	560,867,000	307,672,000	129,401	101,228
Malt	55	97	39,340,000	48,133,000	1,352	2,386
Oil and cake, cotton seed	713	882	570,213,000	212,127,000	26,766	36,838
Oil, linseed	26	25	120,638,000	44,883,000	2,173	1,853
Oilcloth and linoleum, floor	21	18	52,673,000	17,602,000	5,414	4,572
Paper and wood pulp	714	718	794,350,000	332,147,000	113,759	89,916
Phonographs and graphophones	167	18	158,668,000	27,116,000	28,721	10,007
Rice, cleaning and polishing	86	59	90,038,000	23,039,000	2,113	1,852
Soap	352	371	317,067,000	127,942,000	20,436	14,461
Sugar, beet	85	60	149,156,000	62,605,000	11,781	20,353
Sugar, cane	202	181	57,741,000	21,635,000	6,101	14,635
Sugar refining, not including beet sugar	20	18	730,987,000	289,399,000	18,202	12,792
Totals	21,211	22,053	$6,779,449,000	$2,862,605,000	500,194	459,151

		Number	*Capacity, bushels*
Terminal elevators	(b)	339	250,223,122
Country elevators	(b)	21,542	1,076,898,830 (c)

(a) These figures do not include salaried workers and officials.
(b) Licensed by U. S. Grain Corporation.
(c) Estimated.
(d) Includes wheat, rye, corn, buckwheat, barley, oats, grain, alfalfa and similar types of mills.

Among the points and equipment at or from which dust may be produced to get into the plant[1] are the following:

1. At the discharge of the material into the boot of an elevator or into the scale hopper.
2. At the elevator head where it is discharged to cleaners and conveyor belts.
3. At the tripping device.
4. At the cleaners.
5. From dust collectors which exhaust inside the building.
6. From open or leaky spouts.
7. From openings in elevator legs.
8. From the material falling into piles on the floor.
9. From transferring and loading material into cars.
10. From poorly operating equipment.
11. From material falling into open bins.

In short it may be stated that dust is created wherever there is a stirring up, a throwing or a falling of the material.

In addition to points where dusty material is allowed to fall through the air of the plant, as into open bins or onto the floor, the most prolific source of dust in handling equipment is a poorly operated elevator. This is caused in some cases by poorly constructed elevator heads and faulty discharges, and in other cases by incorrect running speeds which allow part of the material elevated to drop back down the leg. This very often creates a "blowing" because a current of air is produced which seeks to force its way out of any opening or crack in the front of the leg and the spouts leading thereto. When an elevator becomes clogged in the "throat" or discharge opening in the head, all the material drops down the back leg and causes a great air pressure within the legs and spouts which in a short time fills the mill with a thick cloud of dust.

Another source of danger from dust is the drying equipment in use. The four types of driers used most generally are the gravity, chamber, tunnel, and the rotary. In the gravity system, used largely for the drying of grain, the product falls gradually through various small chambers with hot air moving in counter currents to the grain, the chambers being so arranged that a considerable part of the air can pass through the comparatively thin layers of grain. In the chamber driers, the material is placed in a large receptacle, and warm air is passed through until the material has been dried to the desired moisture content. This system is often used in drying textiles or other materials through which the air can circulate freely. In the tunnel system the material is placed in the tunnels on trays or in compartments on tracks, being put in at one end and taken out at the other. The warm air moving through the tunnel over and around the material removes the moisture. This system is usually employed in the drying of starch and is coming into use in the dehydration of vegetables, fruits, and other food products. For drying

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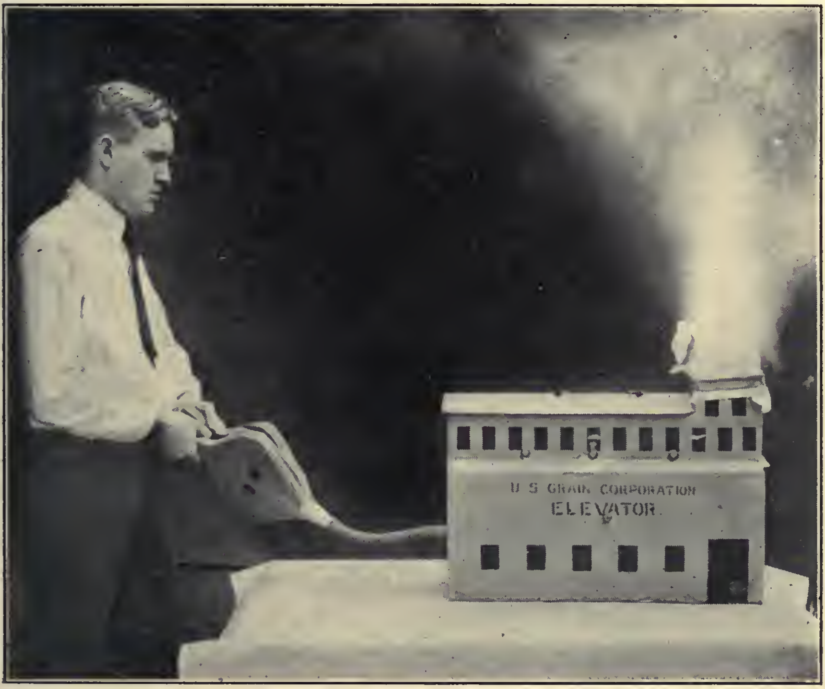
[1] Although these practices relate primarily to plants handling grain, they are generally applicable to representative industries.

products which have a tendency to cake or harden and form a compact mass, such as sugar and fertilizers, rotary driers are employed. The material is kept in agitation as it passes through a large revolving drum containing floats which carry the material toward the top and allow it to fall across the drum and to be again picked up and kept in agitation. It gradually feeds through the revolving drum which is set at a slight angle from the horizontal, while the warm air passes through the drum



The explosibility of carbonaceous dusts can easily be demonstrated in a miniature elevator as shown above. The demonstrator, by means of the hand bellows, has just blown a cloud of dust against an open flame within the sealed compartment. Models of this type were used during the special educational campaign conducted by the U. S. Grain Corporation and the U. S. Department of Agriculture to acquaint operators and workmen with the importance of adopting effective methods of dust explosion prevention.

in counter currents. In all of these drying systems more or less dust is created, but more particularly in the gravity and the rotary systems. However, in the other systems some of the dried material will often fall off the trays or containers and gradually collect in the drier, creating quantities of accumulated dust which may be stirred up at any time and cause an explosion. In all of these systems great care should be taken to see that dust is removed and not allowed to accumulate.

Another operation that is essential in producing a marketable product,

and that is liable to be a source of dust, is the cleaning of raw material. Two means of dry cleaning commonly employed are the screens and the pneumatic cleaners. In both of these systems the material is necessarily kept in agitation, sometimes producing large quantities of dust which if not removed by properly installed dust collecting equipment, will get out into the plant to create a hazardous condition.

After the material has been properly prepared, the next process is the manufacture of the desired products. Pulverizing may be the first step. This can be accomplished in three different general types of machinery which are in common use. One of these, considered as a crushing or grinding machine, is represented by coal crushers or what might be termed jaw crushers and by the ordinary rolls used in the grinding of wheat for flour. In this system material is simply crushed by means of pressure. Another type is the attrition system of pulverizing, in which by very rapid motion with some pressure, the material grinds itself, the various particles rubbing against each other with such force that they are broken down. This system is largely used in the pulverizing of material where a separation is not desired, as for instance in grinding grain for feed, where the entire pulverized material is used in the finished or manufactured product. Another means often used in the grinding of starch and of other food products is that represented by impact pulverizers. A common type is a machine in which a series of hammers is arranged on a rapidly revolving axis so as to strike the material in the drums and gradually pulverize it until it will pass through the meshes of the surrounding screen. In all of these pulverizing processes, quantities of dust are necessarily produced, dependent on the material, and unless the machines are properly enclosed it might get out into the plant. All of the conveying systems from these grinding machines should be tightly enclosed, as in many of them the pressure created will force the dust out through cracks or openings present. It is also advisable to install dust-collecting equipment on each of these machines or at least on the discharge from them so that the fine dust which may have a tendency to get out into the plant may be drawn away and collected. This might also serve as a relief for pressure which may be created in the machine, and by keeping up a circulation of air, as for instance on the rolls used for grinding wheat, they may be kept cool, and dead air may be removed.

Where it is desired to separate any particular material from the pulverized product, or to obtain material of a uniform size, the usual method is to pass the material over some type of screens such as purifiers, bolters or reels. Here the material is kept in agitation, and as it gradually passes through the various screens the desired product is separated. Such a process is sometimes used to obtain a uniform material even though the original material has not necessarily been pulverized. This is the case in the manufacture of dextrine, a comparatively soft and lumpy material. It gradually disintegrates and passes through the screens as it goes through the reels. In all of these machines considerable dust is raised, and care must be taken to see that it does not get out into the plant.

The finished product is usually conveyed to storage bins. Quantities

of dust are necessarily raised by the falling of the material into these bins and more dust is raised as the material is taken out to be packed. Large quantities of dust do not usually arise from the packing of the material, but there is always a little raised as the material falls into the container, such as a bag or a box. If this is allowed to get out into the atmosphere, it will spread throughout the packing department as it is only the light and fine dust which will get out under such conditions. Arrangements should be made to see that all dust is collected and removed at the point where it is created.

The Washburn-Crosby "A" Mill at Minneapolis after the dust explosion of May 2, 1878. This explosion of flour dust, causing the loss of 18 lives and extensive destruction of milling property, is commonly referred to as the first disastrous one in the United States. It brought about the elimination of the old dust or "stive" room in flour milling and the introduction of improved types of dust-collecting equipment.

In most of the industries referred to in Table XVI, one or more of the above steps, if not all of them, are carried out. However, in certain of these there are special processes of manufacture in which dust is created, for instance in the manufacture of powdered aluminum, and also in the polishing or finishing of aluminum goods. The grinding of the aluminum is done in much the same way as the grinding of other materials, but the ground product must be kept dry. If water gets onto this powdered product, oxidation begins immediately, heat is generated, and spontaneous ignition may easily result. If more water is put onto this burning material, the fire is increased rather than extinguished. There

is also the danger of stirring up the pile of powdered material and causing a dust cloud from which an explosion may result. A similar hazard is present in the grinding of magnesium. In the polishing of aluminum, the product is held against rapidly revolving brushes made of fine wire or stiff hair. As in the polishing of other metals, quantities of dust are created which are usually removed through a dust-collecting system. In the case of aluminum the dust created is explosive, while in the polishing of other metals the dust is not so easily oxidized and consequently not explosive.

In cooperage and woodworking plants, considerable dust is created in the finishing of the wood. A comparatively coarse material is obtained in the planing, but fine material goes along with it and creates a cloud of inflammable dust in the suction and dust collector system used for carrying the shavings from the planer. In the turning of the wood to make different shaped articles, as for instance, ax handles, and in the sanding and polishing, large quantities of dust are created. This is usually drawn away through a collector and eventually burned in the furnaces. Unless it is collected, quantities get out into the mill and settle at various places, creating a hazardous condition. There is also a hazard in feeding this material to the boilers if the equipment has not been properly installed, so that no back pressure can be created and flames from the boiler cannot get back into the dust-collecting system.

At first thought it might seem that there would hardly be a place in an edible oil mill where dust would be created and an explosion hazard be present. However, in a cottonseed oil mill, considerable dust is created in delinting the cottonseed before it goes to the cookers. Dust is also created in the conveying and handling of the seed to and from delinters and grinders and to the cookers. Very little dust light and fine enough to float in the atmosphere is created in the processes or in the handling of the material from the cookers to the presses. However, a considerable quantity of dust is created in removing the pressed cake and in the grinding of it. This also applies to other types of mills making edible oils from vegetable products, and to linseed oil mills.

In the manufacture of paper and the handling of the finished product, dust is created in the trimming and edging of the material and especially when the waste is handled pneumatically. This is more particularly true where stones are used in the edging process instead of cutting devices. In mills manufacturing paper from materials other than wood, and especially from rags, quantities of dust are created in cleaning and making them ready for use in the process. In the phonograph and graphophone industries, wood dust is created in making and finishing the cases for the machines, and a very inflammable dust is created in the manufacture of some of the records and in grinding some of the material which goes into the manufacture of them. Dust is also created in the polishing and cutting.

In the process of polishing rice, dextrine and a small amount of moisture are added and the rice is kept in agitation. The rubbing together of

the kernels of rice in the presence of dextrine does the polishing. Naturally a large quantity of dust is created in this process.

An industry on which it has not been possible to obtain any data as to its extent and the value of the products obtained, but in which dangerous dust is created, is the recovery of old rubber and the manufacture of materials, especially hard rubber, therefrom. In this process the old rubber is cut up into small pieces and then finely ground, after which the material goes through a process for the recovery of the rubber. In the grinding operation and in the manufacture of products from hard rubber, a large amount of dust is created.

In all of the industries mentioned, as well as in several others, which it has not been possible to classify in this list, hazardous and dangerous dusts are created in almost all of the steps where a comparatively dry material is handled, especially if handled in bulk and by machinery. It may again be stated that dust is created wherever there is a stirring up, a throwing, or falling of the material, and steps should be taken to remove all of the dust so created and to keep it out of the atmosphere of the plant, and to keep it from accumulating at any point in the mill.

CHAPTER III.

CAUSES OF DUST EXPLOSIONS AND ELIMINATION OF SOURCES OF IGNITION.

In order to have a dust explosion there must be present a proper mixture of inflammable dust and air, and some part of this mixture must come in contact with heat of sufficient intensity to ignite the dust. What may be considered a proper mixture of dust and air and some of the properties which affect the ease with which dusts may be ignited have already been discussed. But there must be some source of ignition. This may be considered to be the real cause of an explosion, and if the sources of ignition can be eliminated explosions will no longer occur.

Frequently when an explosion occurs the press notices state that it was a spontaneous explosion or that it was caused by spontaneous combustion. Either is a convenient expression when the real cause is not known. As a matter of fact many people believe that there is such a thing as a spontaneous explosion, or that dust will ignite spontaneously with a resulting explosion. Their idea seems to be that a pile of dust can be ignited by spontaneous combustion and that when this happens there is an explosion, something like what might be expected should a spark or flame reach dynamite. It must be remembered that dust cannot explode like dynamite or black powder or other detonating explosives, but that dusts explode like gases explode, that is, when intimately mixed with the air as a cloud. Consequently there cannot be such a thing as an explosion of a pile of dust whether flame gets into it or not, as long as the dust remains in the pile. It cannot be denied that there is such a thing as spontaneous combustion. That is too well known. But there is no such thing as spontaneous explosion. When dust is in suspension in the air as a cloud spontaneous heating cannot take place sufficiently to cause combustion, for any such heat, if developed, would immediately be conducted away by the air. The only way in which it is possible to have an explosion from spontaneous combustion is to have a dust cloud come in contact with a hot coal or flame which may have been caused by spontaneous combustion. These facts explain in a general way the meaning of the term "spontaneous combustion." But there is one investigator who,

as a result of a long series of experiments, believes that dust may be able to fire itself. A discussion of this theory will be reserved for a later chapter on "Static Electricity." So far as is known no explosion has started in this way.

It is quite possible that it may be said after reading this chapter that there is nothing new in it. That may be granted from the first, for there is no new source of heat, but at least the various sources of ignition of dusts should be known. It has been shown that it is possible to ignite some dusts at a very low temperature, in fact at temperatures well below dull redness of iron. It would therefore be expected that an explosion would be possible wherever there might be present a source of heat of 500° C. (932° F.), or even lower under some conditions, if dust were present. Some of these sources of ignition may not be considered in this chapter for only the more frequent causes of explosions will be discussed, but they should not be forgotten.

A dust explosion on September 12, 1919, in this feed grinding plant in Buffalo, N. Y., damaged property to the extent of $20,000 and caused injuries to 3 workmen.

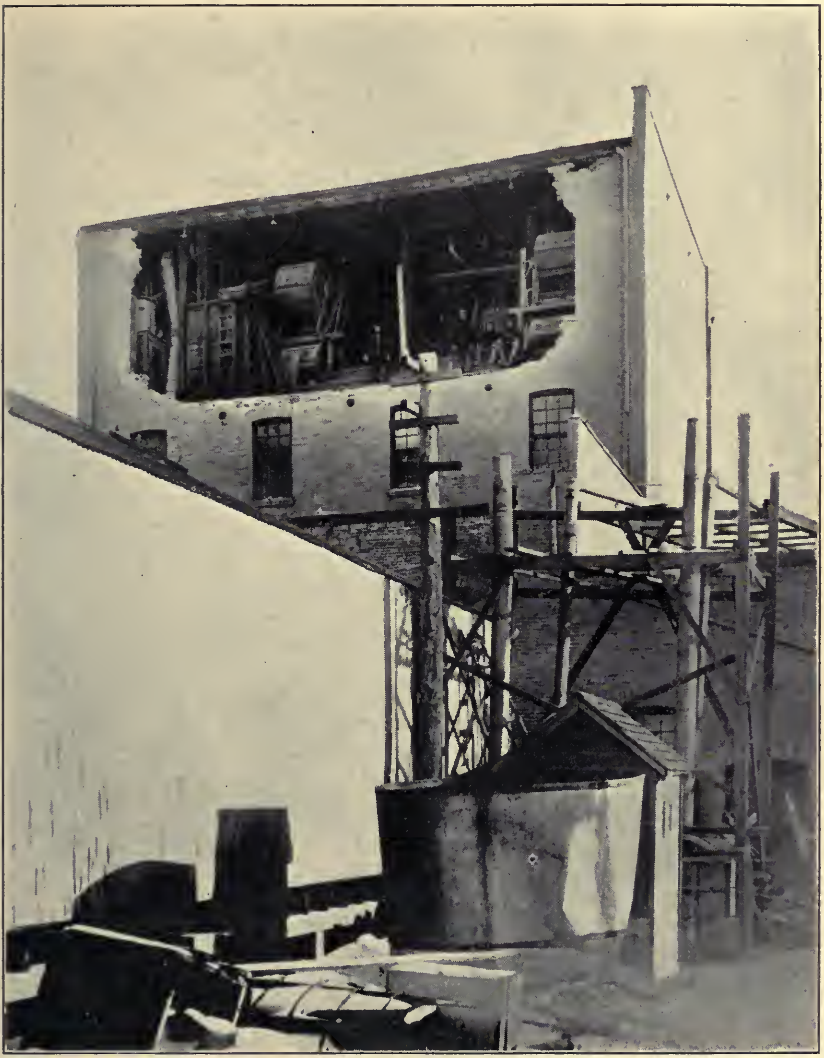
In considering the causes, and means of eliminating them, which seem to call for special attention no lengthy discussion will be attempted. A few facts and illustrations should be sufficient for the average man and others learn only through the school of hard experience. These various causes will not be discussed in the order of their importance, or with any particular reference to their relative hazard or the number of explosions which may have been caused by them.

1. *Smoking and matches.*—Explosions and fires have been started by the striking of matches or by men smoking in plants. The danger of fire from these causes has been appreciated more fully than has the danger of explosions. This may have been a result, in part at least, of the lack of knowledge on the part of employees, but it is hard to understand why

this is true with many employers as well. Their interests should convince them that the use of cigarettes, cigars, pipes and matches in and around plants where combustible materials and especially inflammable dusts are present is dangerous. This practice has been responsible for so many dust explosions and fires that the relative danger of matches and smoking as a cause of explosions and fires is no longer debatable. The cold facts on record of losses of life and property from this unnecessary cause should be sufficient warning for every operator and workman in industrial plants where dangerous dusts are present, and in fact in all plants, to refrain from smoking. Often an official of a mill will be smoking when an inspector or visitor arrives at the office and will either continue to do so during the trip about or, if he doesn't actually smoke, will keep his cigar in his mouth unlighted. For its effect upon the employees this is almost, if not wholly, as bad as smoking, for a wrong impression is gained. That the official had a cigar in his mouth is the same thing to them as smoking. They take this incident, and not unjustifiably, as a license to them to smoke. If the men have to smoke, then places should be provided for it and they should not be allowed even to carry matches into the plant. Though this may not be a temptation to smoke, if the men have matches and get into dark places or the regular lights fail the first inclination is to think of the light nearest at hand, the match. It is lighted thoughtlessly and the trouble starts.

For instance, a man went to a bin in a flour mill in a Western State to see how much flour was there. He could not see readily on account of the dust raised by the incoming flour, and as there was no electric light handy it was concluded that he struck a match and put it into the bin for a light. An explosion occurred which blew out the side of the building and nearly caused the employee to lose his life. In a very similar case in Western Canada a plant was destroyed almost completely and the employee responsible was burned seriously. This time it was a returned soldier who had been through four years of fighting in Europe. War didn't get him but carelessness or thoughtlessness nearly did. However, it is not always the lighting of the match which causes the trouble. The coal on a cigarette or cigar or in a pipe may do as much harm. A man in a southern mill wanted to know the contents of a flour bin. When he opened the door of the bin he did not have time to light a match, for as soon as the cloud of dust which came out reached his pipe it became ignited and a slight explosion resulted. Fortunately the mill was clean and the door fell shut before the explosion got into the bin, but the man was burned badly and the scorched boards by the bin door today bear silent tribute to this miller's carelessness. He says that he has had his lesson and therefore allows no smoking anywhere around his mill.

It should not be necessary to mention any more explosions of this sort, though others have been more disastrous, but it might not be out of place to refer to one other involving a different kind of dust and resulting in a different type of explosion. In March, 1918, a workman in the Jarvis Warehouse in Jersey City, N. J., threw a lighted cigarette stub on the floor. At the time he and four other men were handling loose chlorate



This photograph shows the damage caused by an explosion in a flour mill in Boissevain, Manitoba, when an employee struck a match to determine the amount of flour in a packer bin. A large number of dust explosions in industrial plants have occurred as a result of this practice.

of potash. A fire quickly started in the highly combustible combination of wood, flour, chlorate dust and the coal of the cigarette. The workman tried to stamp it out and an explosion resulted. The fire spread rapidly beyond control so that the entire warehouse together with the Erie

machine shops was destroyed. The approximate loss amounted to over $2,000,000.00, quite a price to pay for a little smoke.

Too many disastrous explosions have been chargeable to smoking or to the use of matches in plants. It is almost impossible, without rigid rules, enforcement and inspection, to prevent the men from carrying matches and from smoking occasionally. However, extreme preventive measures should be adopted and enforced. The authors, from repeated experiences with workmen in various mills, feel that this practice is largely a result of the employee's being ignorant of the hazard. It has been found, in the majority of cases, that when a man realizes the possible results and the dangers which his carelessness may bring to himself and his employer, he will not carry matches nor smoke in the mill. Rules and regulations rigidly enforced are good and a place for smoking should be provided, but education of the average workman will do more to prevent fires and explosions than any other one thing. He should not only be told but have demonstrated to him what may be the result of striking a match or smoking in the mill. The greater safety in using the match which can be struck only on the box over the kind which can be struck anywhere should be emphasized. Neither should be allowed, but there is an element of safety in the former which the latter does not have. The necessity for this prevention of smoking and the carrying of matches cannot be emphasized too strongly.

2. *Use of Open Flames and Naked Lights.*—A large number of explosions and fires have been caused by the introduction or use of open flames and naked lights in dusty atmospheres. In this class may be included the following:—(a) lamps, (b) torches of various kinds, (c) lanterns, (d) gas lights and (e) candles. The flames of matches might be included, also.

Although at the present time in many modern industrial plants the use of open flames of any kind is prohibited, it has been found that the practice prevails in a large number of factories, especially in plants of smaller capacity. When such a system of lighting is found in a small community where there is no electricity, and is called to the attention of the operator he may say that he understands or has heard that the open flame has caused trouble but that he hasn't found any other way of lighting. This is a poor excuse for the small electric lighting units on the market can be installed and operated at a comparatively small expense. As a matter of fact, the amount invested would be cheap insurance even though a lower rate might not be obtained on the property for some good reason. In some plants with modern lighting systems the oil lantern is still in use for some purposes. The old habit of introducing it into grain bins persists around some mills and elevators to such an extent that many milling and grain men point to this as a reason for their opinion that there is not much danger in the practice, stating that, if there were, they could not have carried it on so long without having trouble. This is not well founded, however, for many explosions have been caused by the open flame.

All types of open flames will ignite inflammable dusts under the right conditions. This means not only flames which are entirely unprotected, as an ordinary fishtail gas flame, or the flame of a match, but also protected flames, as in lanterns or inclosed Welsbach gas lights. A flame must have air to support its combustion. If there is dust in the air, it will be drawn to the flame with the air and ignited, and an explosion will follow if sufficient dust is present. Consequently, all protected and unprotected flames must be kept out of industrial plants where there is inflammable dust if explosions are to be prevented.

A disastrous explosion in a starch factory was caused by the use of a lantern while cleaning out the starch driers. Fortunately workmen

During the progress of a fire in this spice plant in Cincinnati, Ohio, an explosion occurred. As a result of the explosion 4 firemen were killed and 13 injured. The ignition of spice dust by the flames from the fire was assigned as one of the possible causes of the explosion.

who saw the starting of this explosion were not killed, though there was extensive loss of property. One of them stated that he noticed the particles of starch dust circulating round and round the lantern, then, as he put it, "the air all round the lantern took fire," and the flame surrounded him. The portion of the plant where the explosion started was damaged slightly while more distant portions were destroyed. In another case two workmen in a paper mill were not so fortunate. They were cleaning out a dust room where dust from the grinding of the paper edges was blown. The cloud which they stirred up in the cleaning came in contact with the lantern. A serious explosion resulted and both men lost their lives. A few years ago in Glasgow, Scotland, dust which had ac-

cumulated on beams and rafters in a provender mill, grinding peas, beans, wheat, etc., became dislodged and fell as a cloud upon an open gas flame. Several people lost their lives in the explosion which followed.

It often happens that a bearing has to be babbitted or other work has to be done in a plant, requiring the use of a small hot flame, as a plumber's torch. This should not be allowed, unless it is absolutely impossible to do the work outside of the plant. In this case it should be done only under the most strict regulations. The mill should not only be closed down, but there should be nothing going on in the plant which would create dust or make a dust cloud. For instance, a set of rolls was being babbitted in a flour mill in the State of Washington, the babbit being melted by the flame of a plumber's torch. At the same time a man was sweeping up the dust on a floor above. A cloud of dust reached the torch, with the result that the mill was destroyed by an explosion and fire. At another time, in a mill in Buffalo, N. Y., which had shut down, a hole was being cut in the steel boot of an elevator with an oxyacetylene flame. After the cutting had been completed and the flame turned out, and while the operator was waiting for the metal to cool, a man started to work on the casing at the head of the elevator. While hammering, a dust cloud was stirred up inside the elevator and an explosion resulted from the ignition of the dust by the hot steel.

Many more illustrations could be given but these should convince any one that the *open flame,* be it a lantern or any other type, *must go* so far as its use is concerned in industrial plants where inflammable material is present. The use of open flames for lighting purposes, their introduction into dusty atmospheres or the carrying of open lanterns into the plant either during its operation or by the night watchman are dangerous practices and should be prohibited and prevented.

3. *Small-scale fires.*—Several explosions of large proportions have resulted from fires in industrial plants. The flames from the fire produce sufficient draft to throw the dust into suspension and thereby create a dust cloud which explodes when the flame reaches it. Sometimes a falling timber or the caving-in of the walls, floors or roof will throw dust into suspension, forming the dust cloud. If a plant is dusty and dirty, a dangerous condition is brought about during a fire. For instance, if a fire should start in a plant where there is a coating of dust on the walls, it would spread very rapidly over the surface of the dust. This is equally true of dust on the floor or in any other part of the plant, and especially when the surface is increased by numberless or even a few cobwebs. This is due not only to the natural tendency of fire to spread rapidly through inflammable materials, but when once started the flame creates a draft which immediately precedes it and raises a small cloud of dust which feeds the flame and aids its rapid travel over the surface. In this way the flame spreads throughout the immediate open section of the plant. Too often it is reported that the fire was beyond control in a very few moments. This can be partly accounted for by the rapid spread of the flame through dust. If for no other reason than that of the fire hazard,

all industrial plants should be kept clean and dust should not be allowed to accumulate.

But there is also the explosion hazard of the dust during the progress of the fire. For instance, a fire had been in progress in a plant in Litchfield, Ill., for fully 30 minutes when some timbers fell, apparently throwing quantities of dust into suspension, for one of the most violent explosions on record occurred immediately, and the plant was completely

Fire followed a dust explosion in this elevator at Richford, Vt., on October 7, 1908. The property was extensively damaged; 15 employees lost their lives and 2 women who were walking on the tracks outside the plant were fatally burned.

destroyed. A similar but less violent explosion occurred during the progress of a fire in an elevator in Indiana in June, 1918.

Once a fire has gone over the surface it will take considerable time for a pile of dust to burn because a smoldering layer of carbonized dust and ash forms over the top. But if the dust is stirred up and thrown into suspension an explosion usually occurs. This may happen during the fighting of a fire. The stream from the hose may strike a pile of dust and throw it into suspension. Such an explosion occurred in 1918 during the progress of a fire in a linoleum factory in Philadelphia. A stream of water struck into the cork dust in the dust room throwing it into suspension as the fire was burning in and around the room. The result was a terrific explosion in which several firemen were injured. Care should be taken in fighting a fire in an industrial plant where inflammable dust is known to be present not to stir up the dust any more than is necessary. If it is possible to determine the location of the larger accumulations of dust, these should be wet down by directing the stream of water over and not toward them.

With this thought in mind it is easy to conceive of the possibility

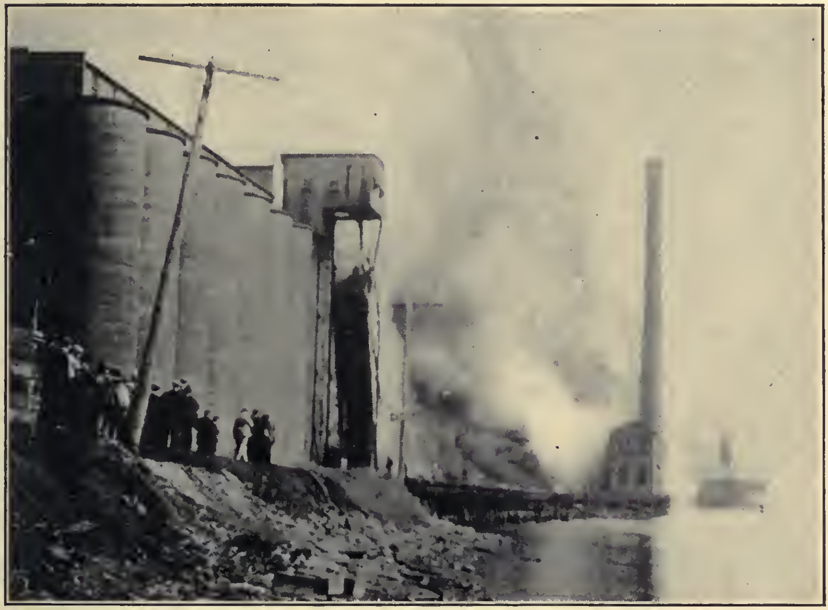
that many of the so-called smoke explosions which have occurred during the progress of fires, have been dust explosions. There is such a thing as a smoke explosion and also such a thing as a dust explosion during the progress of a fire, however, and they should not be confused. The former occurs when heat and incomplete combustion cause distillation of gases which explode with violence when they become mixed with air in the proper proportions in the presence of fire. The latter occurs when the dust, thrown into suspension and mixed with the air, comes in contact with the flame. It is difficult to prevent the smoke explosion under certain conditions, except by giving ventilation to the gases, but the dust explosion can be prevented by keeping the plant clean and in that way only.

As all fires have small beginnings, a discussion of the prevention of small-scale fires might properly include the entire question of fire prevention. This will not be undertaken, however, since most readers of this book are already familiar with the subject and many phases will be discussed elsewhere. However, there are two points which should be emphasized here, namely, good housekeeping and fire-resistive construction. These should go hand in hand, for even in a fire-resistive building the fire may reach large proportions and the plant be destroyed unless it is well kept. It is possible, also, that a well-kept house of inflammable construction may be destroyed, but the destruction will not be as easy nor as rapid as in a poorly kept house. Good housekeeping is also one of the primary requisites in the prevention of dust explosions, for they cannot propagate through a clean plant. With dust as a medium, even a thin coating over the floor, walls, etc., a fire may spread very rapidly. If, in spite of all precautions against fire, a small one starts from some unexpected cause, it can not grow to one of large proportions if the plant is clean. Therefore, regardless of the type of construction of the building, the plant must be kept scrupulously clean. Though an explosion may wreck a structure, if it is of fire-resistive construction, there will be little material to burn and it will not be as completely destroyed as in the case of a wooden structure. It is possible that a well-kept mill of fire-resistive construction may be destroyed by a dust explosion, but the chances are decidedly in its favor since there is less opportunity for a fire to gain headway or an explosion to propagate.

There should be no need to call attention to the advisability of installing effective fire-fighting equipment, as this is one of the primary principles of safety. Any type of equipment is practically, if not wholly, useless after an explosion is well under way, but fire extinguishers and automatic sprinklers will help to put out the small fire which may start an explosion and the fires which follow a minor explosion.

4. *Electrical Causes.*—Considerable attention has been given to the starting of fires from electrical causes and a carefully drawn code (National Electrical Code) is followed in making electrical installations. Effective regulations which have been formulated to protect property against fire should be followed in considering installations to insure the greatest possible protection against explosions. Extra precautions

should be taken where there is electrical equipment in a location where inflammable dust may be present. For some time there seemed to be a question whether an electrical spark would ignite dust or not. However, it is now known that a much smaller spark than was ever thought possible will ignite some dusts. In fact several very disastrous explosions have been traced directly to electrical causes, such as sparks from motors, fuses, switches, short circuits, etc., and to the breaking of incandescent



Spectators watching the destruction by the fire that followed a dust explosion in a large terminal grain elevator in Baltimore, Md., June 13, 1916. The explosion was caused by a "choke-up" in an elevator leg and resulted in the loss of 7 lives, injuries to 22 workmen and property and grain damage of approximately $1,500,000.

light bulbs. A number of fires have been caused by dust collecting and accumulating on electric light bulbs.

The most disastrous dust explosion which ever occurred in an industrial plant in England was assigned to the blowing of an uncovered fuse on a temporary switchboard at the very moment when a large belt broke and stirred up a dense cloud of the dust which had been allowed to accumulate in that portion of the plant. Thirty-nine men lost their lives and 101 were injured. Two men were seriously injured by a small explosion in a starch factory in Illinois when they lowered an unprotected extension light into a starch bin and allowed it to strike against the sides of the bin. While the exact cause of a very disastrous explosion in an elevator in Kansas City may never be determined, at the point where it started the cord on one of the drop lights was frayed badly and the

globe was broken. The cord looked as though a short circuit might have occurred, but in any case either the short circuit or the breaking of the globe could have started this explosion. More incidents might be mentioned where these and other similar causes have been responsible for disastrous explosions, but those given will indicate some of the possibilities and suggest some of the remedies.

There can be no question but that the incandescent electric light is the safest and best type of light which we have today for industrial plants, but it would seem that some changes from the usual practices in its use should be made. This feeling has been growing as a result of the number of explosions and fires which may be traced to them as a possible cause. With this in mind, investigations were conducted cooperatively by the various electric lamp manufacturers and the Bureau of Chemistry at the laboratories of the National Electric Lamp Works at Nela Park, Cleveland, Ohio.[1]

The possibility of fires or explosions from incandescent lamps in dusty atmospheres, such as are usually found in the handling of grain, starch, flour, sugar, and similar carbonaceous dusts may be classified under two distinct heads:

(1) Explosions caused by breakage of incandescent lamps in an atmosphere which has the proper proportions of dust and air to make it explosive.

(2) Fires directly caused by ignition of dust collecting on lamp bulbs.

Explosions from Broken Lamps.

The first classification is by far the more important of the two considerations. It has already been shown that nearly all dusts having a high carbon content and being finely divided may be exploded by an open flame when such dusts are combined with air in the right proportion. It has also been shown that the electric arc or static electricity can start an explosion. These facts have all been verified and in addition it has been shown that explosions under the same conditions may be obtained when an incandescent lamp is broken or demolished in a dust cloud. Both vacuum and gas-filled lamps will give the same results; the only exceptions noted so far have been with very low-wattage vacuum tungsten and carbon lamps. These lamps, however, are not excluded on this account because much depends on the character of the dust cloud and the manner in which the lamps are broken. If the cloud has the proper proportions of dust and air, it is exploded when coming in contact with any lighted source such as a match, candle, lantern, or other flame.

These tests were made in an explosion chamber constructed according to the diagram shown in Fig. 14. A socket to hold lamps of various sizes

[1] The tests were conducted in co-operation with the National Lamp Works of the General Electric Co., Cleveland, Ohio; Edison Lamp Works of the General Electric Co., Harrison, N. J.; and Westinghouse Lamp Co., Bloomfield, N. J. The lamp testing work was carried on in the Nela Park laboratories of the National Lamp Works by C. L. Dows, assisted by H. G. Hills.

was placed in the bottom of the chamber and a rod, with trigger release, arranged to break the lamp when a dust cloud had been formed in the chamber. The cloud was produced by blowing dust from small shelves

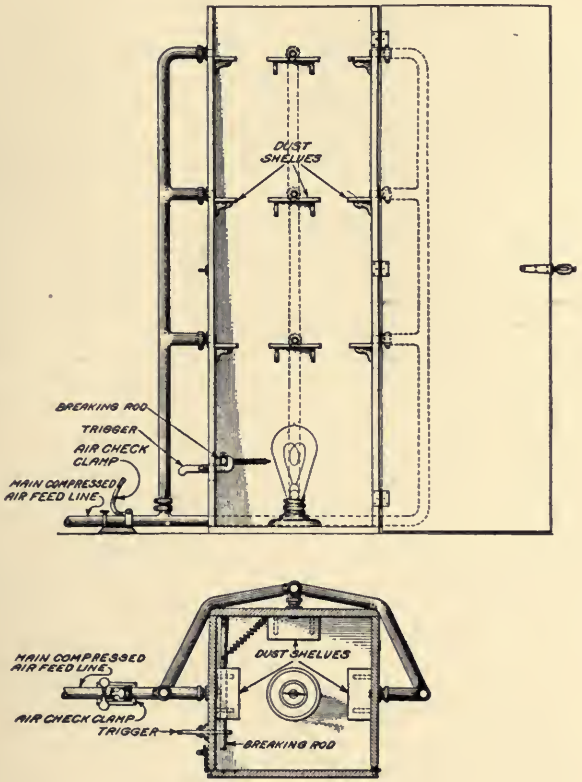


Fig. 14.
Explosion Chamber.

along the side of the chamber. As this dust settled, the trigger was pulled, and the rod, springing back to its normal position, broke the globe.

The breaking of incandescent lamp bulbs except by accident or careless usage is rare indeed. There are, however, certain practices in use in elevators which in view of the risk involved must be considered exceedingly dangerous. One of these is the lowering of an unprotected lamp bulb into an elevator bin to determine the amount of grain or feed it contains. The mechanical breaking of the bulb, or a short-circuit in the socket or wire, or the flash from a loose connection, may easily be sufficient to produce a disastrous explosion under the right conditions. This and other similar practices should be discontinued.

Fires from Dust on Lamp Bulbs.

During a special dust explosion prevention campaign conducted by the U. S. Department of Agriculture and the U. S. Grain Corporation the field men visiting the mills and elevators obtained numerous reports of fires assigned to dust collecting on electric lamp bulbs. A number of cases were reported where the explosion or fire was supposed to have been started by the ignition of dust which had settled on the lamp.

It has been known for some time that fires could be readily started by burying an electric lamp in dust. In tests conducted at the Pittsburgh station of the Bureau of Mines a 32 candlepower electric lamp was placed in a box of fine coal dust. In less than 30 minutes the bulb had burst and the coal dust was found to be on fire. Following this experiment a 16 candlepower electric lamp was placed in a nail keg half filled with Pittsburgh coal dust. Eighteen minutes later small puffs of smoke issued from the keg and at the end of 32 minutes the dust smoked steadily, continuing to burn even after the lamp had been removed.

The manager of a large grain elevator in the Northwest reported to the Department of Agriculture that the dust which collects on electric lamps often smolders and smokes and sometimes ignites and glows. He reported further that the dust coating on the globe had been known to take fire and drop to the floor, igniting dust there.

Another elevator company reported that three fires had started in the plant within 5 feet of one another at intervals of one hour. As various theories concerning the origin of the fire were advanced, a detailed investigation was undertaken. It was found that the fires were caused by the collection of wheat dust on ordinary incandescent lamps. Appar-

TABLE XVII.

SMOKING, MELTING, AND IGNITION TEMPERATURES OF CARBONACEOUS DUSTS.

Name of dust.	Smoking temperature.		Melting temperature.[1]		Ignition temperature.		Differences between smoking and ignition temperatures.	
	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.
Sample 2[2]	288	142	...	...	511	266	233	124
Sample 1[3]	331	166	...	...	513	267	182	101
Sample 4[4]	295	146	...	...	532	278	237	132
Sample 3[5]	298	148	...	...	536	280	238	132
Cocoa	313	156	...	...	558	292	245	136
Graham flour	309	154	552	289	883	473	574	319
Cornstarch	284	140	545	285	891	477	607	337
White wheat flour	315	157	507	264	919	493	604	336
Corn meal	311	155	527	275	934	501	623	346

[1] Melting temperature is considered to be the point at which the dust becomes sticky or congeals.
[2] Approximately 22 per cent oats, 20 per cent durum, 40 per cent winter wheat, 10 per cent hard winter wheat, 10 per cent miscellaneous.
[3] Durum wheat dust.
[4] Approximately 40 per cent winter wheat, 35 per cent barley, 25 per cent oats.
[5] Approximately 60 per cent oats, 35 per cent winter wheat, 5 per cent rye.

ently the dust was ignited by the heat of the globe and fell to the floor, where it set fire to dust. The trouble was remedied by the installation of double globes on the lamps.

Experimental Work.

In the tests conducted in cooperation with the lamp manufacturing companies in order to ascertain the danger due to the ignition of the dust on the globe more extensive investigations were necessary. Practically all of the carbonaceous dusts found in the milling and allied industries, some of which are mentioned above, will smoke and give off

TABLE XVIII.

BARE LAMP TEMPERATURES.[1]

Type of lamp.	Maximum bulb temperature.		Temperature opposite filament.	
	°F.	°C.	°F.	°C.
Vacuum:				
50-watt	153	67	153	67
100-watt	152	67	152	67
150-watt	157	69	156	69
Gas-filled:				
75-watt	245	118	180	82
100-watt	259	126	178	81
150-watt	338	170	222	106
200-watt	327	164	222	106
300-watt	294	146	229	109

[1] Values are averages of several tests.

Conclusions from Tables XVII and XVIII.

Ignition temperatures extra chaffy dusts—511° to 558° F. (266° to 292° C.).
Ignition temperatures other dusts—883° to 934° F. (473° to 501° C.).
Dust therefore must be raised over 150 Fahrenheit degrees (83 Centigrade degrees) to cause ignition.

an odor if they are allowed to collect on the bulb of a gas-filled lamp. This phenomenon was at first considered as indicative of danger because smoke was generally interpreted as representing a fire. It was found, however, that there is a substantial margin between the smoking and ignition temperature. This margin may be safe or unsafe, depending on the ignition temperature and character of the dusts, and the temperature of the heated body on which the dust collects. It is very much less in some cases than in others. Temperature readings of the various types of vacuum and gas-filled lamps on the market were compared with the ignition temperatures of the various dusts found in our industrial plants. Tables XVII and XVIII give the temperature readings for representative types of lamps, as well as the smoking, melting and ignition temperatures

of various dusts. It will be noted that the temperature of the dust must be raised at least 150 Fahrenheit degrees above the maximum temperature of the bulb to cause ignition.

RESULTS.

In an especially constructed chamber in which a continuous dust cloud may be maintained it has been possible to start a fire on the larger gas-filled lamps with each of the first four samples listed in Table XVII.

The ignition of these dusts is probably due to the fact that the very chaffy dusts collect on the globe, where they form a blanket which prevents radiation of the heat generated in the lamp and raises the temperature of the bulb to the ignition temperature of the dust. Some dusts seem to melt or congeal and form on the globe a crust which does not burn readily. Other dusts apparently do not form a blanket heavy enough to cause the temperature of the bulb to be raised to their ignition temperature. It is believed, however, that any combustible dust if allowed to collect on the lamp in sufficiently thick layers and remain long enough will ignite. Under ordinary conditions with the small lamps commonly used in our industrial plants and with free circulation of air around the globe, it is thought unlikely that a fire will be readily started in this way. It is, however, a hazard which should be guarded against.

CONCLUSIONS: It is hoped that those interested in this subject will give serious consideration to the improvement of the electrical equipment in grain elevators and mills, as it is only through such combined effort that progress can be made.

Although this illuminant as it is now generally used is unquestionably a hazard, it must be remembered that it is the safest source available, and when properly used affords a solution of the problem. The habit of using drop cords and portable electric lights is probably the most common objectionable practice.

It must always be remembered that a fire may be started with any incandescent electric lamp, vacuum or gas-filled, or for that matter, with any device which changes energy from one form to another, if it is operated continuously when so surrounded that the heat must accumulate. Under these conditions, the continuous accumulation of heat energy, the temperature of the surrounding material will steadily rise until it reaches a temperature at which the energy is dissipated as rapidly as it is supplied, and if this final limiting temperature is sufficiently high, a fire may be expected as a natural result if combustible materials are present.

The results of these tests show that no electric lamps should be allowed to become thickly coated with dust, first because of the danger of fire and second because of the great loss in illuminating value. In some cases, lamps actually become buried in the grain, and the hazard under such conditions is extremely great.

There are on the market many types of so-called marine or vapor-proof fixtures, which are designed for use in locations where explosive

gases are prevalent, or where the fixtures are subjected to moisture. Tests have been conducted on a few types of these fixtures to ascertain whether the temperature of the enclosing globe is sufficiently low to prevent the ignition of dust when gas-filled lamps are used. The tests conducted up to the present time indicate that globes having straight sides, which tend to prevent the accumulation of dust, and which are of sufficient diameter, may be used with gas-filled lamps and yet maintain a temperature below the smoking temperatures given in Table XVII. These tests

This plant at Waukegan, Ill., was completely wrecked by an explosion of dextrine dust on November 25, 1912. Fourteen employees were killed, 19 injured and considerable property damage done.

included vacuum lamps up to 100 watts and gas-filled lamps up to 200 watts, and in no case did the final temperature approach to within 75° F. (42° C.) of the lowest smoking temperature of any of the samples listed. In general, the temperature of the usual exposed type of vapor-proof unit is about half that of the bare lamp which it houses and is therefore within the range of vacuum lamp bulb temperatures. This low temperature is attained at the expense of a higher operating temperature of the lamp within the unit; the advantage, however, of lower temperature of the exposed surface is obvious. In view of these tests, it appears at this time that with properly selected enclosing globes, gas-filled lamps up to 200 watts may be used with safety as far as fire is concerned.

All incandescent lamps should be protected against breakage wherever there is danger of an explosive dust cloud. Good vapor-proof fixtures are a long step in the right direction and their effectiveness can be increased

by the use of a suitable wire guard or other protecting device. The point to be remembered is that it should not be possible for the filament of the lamp to become exposed to the dusty atmosphere under any conceivable condition.

An investigation should be made of the methods now employed in the lighting of grain elevators with the idea of making recommendations not only as to equipment which can be safely used, but also as to the amount of illumination required. To date it appears that many of the dangerous practices, such as the use of open wiring, drop cords, unprotected lights, etc., can be eliminated by modern lighting methods. The statistics of insurance companies have shown that out of 91,000 industrial accidents investigated, 23.8 per cent were due directly to inadequate illumination. The hazards of most industries can be greatly reduced through proper lighting and the introduction of various safeguards, and there is no good reason why similar results should not be obtained in this particular industry. For example, statistics available show that six times as many fires occur in dirty mills and elevators as in clean ones.

The incandescent lamp is by far the safest illuminant in existence for use in dusty locations, but its application has been given little attention up to the present time. Properly installed and properly used, it will be found to fill all requirements.

It should not be necessary here to go into detail regarding methods of prevention of electrical causes of dust explosions. The same electrical sources of ignition that start fires will start explosions. Various electrical codes have been drawn up to insure safe installation and operation of all electrical equipment. Too great care cannot be exercised in seeing that any electrical equipment is properly installed. But often the fact that the equipment will wear out seems to be forgotten, and proper attention is not given to it after installation. Motors are allowed to run hot, to get dirty and to spark; doors to switch and fuse boxes get broken and are not replaced; extension cords become frayed and the insulation gets worn nearly if not entirely through; extension and other lights located where they may get broken are used without guards; and dust is allowed to accumulate upon the light globes. These are a few of the more common lax practices tolerated in many mills. All electrical equipment should be kept in perfect order, and none of the above conditions should be allowed under any consideration. Electric sparks of all kinds, short circuits, arcs, the breaking of incandescent light globes and the blowing of fuses, all may ignite dust and cause explosions.

It has been shown that under certain conditions a fire may result from the ignition of the dust which accumulates upon the sides of the globes of incandescent lamps. The breaking of a globe in a dusty atmosphere may also ignite the dust and start an explosion. To guard against this danger, all incandescent lamps in dusty atmospheres should be inclosed in vapor-proof globes of the so-called marine type. These are designed for use where explosive gases are present or where the fixtures are subjected to moisture. If there is the slightest danger of breakage a lamp should be heavily protected, so that it could not be broken even

though it received a sudden, hard blow. The incandescent electric lamp is the safest lighting equipment in existence for use in dusty atmospheres, but too little attention has been given to its application, installation and maintenance. Properly installed, used and maintained it introduces only a slight hazard, but the above precautions should be taken.

An explosion of hard-rubber dust in this plant at Muskegon, Mich., on August 18, 1920, killed 9 men and badly damaged the section shown. This type of explosion emphasized the importance of adopting effective control methods in industrial plants.

5. *Sparks from Foreign Material in Grinding Machines.*—In a large number of explosions which have occurred in plants grinding grains, spices and other carbonaceous materials, the origin appears to have been in the interior of the grinding machine. These explosions, some of which are the most disastrous on record, have not been confined to any one kind of grinder, but have occurred in practically every type known to the authors, in rolls of flour mills, in attrition mills of feed mills and in the hammer type of grinders used in various industries. Although in most modern mills provision is made for the removal of foreign material, such as pieces of metal, stones, etc., either by separators or magnets, at times some of it gets by and into the grinding machine. When it comes in contact with the grinding surfaces of the machine a series of sparks is produced which it is thought ignites the dust and initiates the explosion.

It was thought that the cause of a disastrous explosion in a feed mill in Buffalo, in 1913, could be traced to this source, while in the case of another explosion in the same city a few months later there was no doubt that this was the cause. In these two explosions many persons

lost their lives and several were injured. A few years ago there was a very disastrous explosion in a feed and cereal mill in Peterborough, Ontario, the cause of which was quite definitely traced to foreign material striking the plates of an attrition mill grinding oat hulls for feed. In this explosion 17 lost their lives and 16 were injured, and the entire plant was destroyed. In October, 1914, one of the authors visited the plant of the Postum Cereal Company in Battle Creek, Mich. On reaching the flour-milling portion of the plant the head miller said: "You ought to have been here Saturday." On being asked why, he pointed to a set of rolls. He said he had heard something which sounded like a nail or screw sliding down the metal-lined spout with the wheat. When it struck the rolls an explosion took place under them. The doors were blown open and flame shot out 10 feet or more in all directions. As there was no dust around to be stirred up and ignited, the flame receded and continued to burn under the rolls until the feed was shut off and the mill shut down. This incident is given in detail to show what may happen and how a disastrous explosion may be initiated. It is possible to determine the cause of such minor explosions more readily than it is the more disastrous ones for the evidence is not wiped out, or as in this case, the one person who saw it start was able to give details of what happened. This man said that in his more than 20 years' experience in milling he had not heard of such a thing and that he would not have believed it possible if he had not seen it with his own eyes.

In Department of Agriculture Bulletin 681 there are published the results of a co-operative investigation between the Department and Pennsylvania State College to determine the circumstances under which explosions might be started in this way. An attrition mill was used and nails, flint stones, etc., were fed into the machine along with the product to be ground. It was found that a cloud of sufficient density to explode was always present within the casing of the machine, and that this could be ignited easily by an open flame or an electric arc, but during the short duration of each series of tests conditions were not obtained whereby an explosion was started from the sparks struck by the foreign material going through the plates of the machine.

This seemed to be one of those things hard to "make happen" but which occur so easily and unexpectedly in normal operation. The mere fact that an explosion was not obtained in the tests really proves nothing. No doubt many pieces of foreign material pass through grinding machines and no explosion results, but as many explosions have happened from this cause every precaution should be taken to prevent foreign material from entering grinding machines.

In the handling of grains or other materials, many foreign substances such as pieces of metal, nails, bolts, screws, etc., and small stones may get into them before they reach the mill. If they are not removed before reaching the grinders, the sparks which will be struck as they pass through may ignite the dust within the machines, causing explosions. Only by removing completely all foreign materials can explosions from this cause be prevented. Although much of this work is done in the various clean-

Results of an explosion of gluten feed on August 7, 1910, in an elevator in Granite City, Ill. The dust was ignited in a grinding machine and the explosion propagated through the 10-inch steel trunking shown in the illustration, for a distance of approximately 375 feet, to the top of the elevator where the explosion occurred. Two men were killed and 7 injured.

ing processes to which the product to be ground is subjected, it sometimes is not possible to remove all foreign substances. Magnetic separators should be installed just ahead of the grinders to remove the last of the metallic particles. Even these might allow a piece of material to get by if it should be riding on top of the stream of grain or other material so that the magnet could not pull it down through the intervening material. In order to be wholly effective in removing the metallic substances, the stream running over the magnets should be so thin that each piece of metal could come in contact with the magnetized surface.

Most of the small stones and the non-metallic material will be removed in the cleaning devices, but, as in the case of the metallic substances, some may get by. One of the best ways to remove these is by air separation. Being heavier, as a rule, than the product to be ground, this material will fall out if an air current is used to carry the product over a depression or opening. One method of air separation is to blow the product into a bin several feet away from the air conveyor and to have a smaller bin between into which the heavier materials will fall. Another method is to allow the product to drop straight down through a semicircular or rectangular shaped pipe and to have sufficient suction in a similar pipe adjoining to draw it up again, while the heavier material drops out at the bottom. This method has the advantage of creating less dust but, on the other hand, less product can be handled in any given time. It is evident that some method of air separation should be installed in every mill in which the grinding of inflammable materials is carried on. It is only by the complete removal of all foreign materials that explosions from this cause can be prevented.

6. *Static Electricity.*—Too little attention has been given in the past to the presence of static electricity in our industrial plants, and especially where inflammable material, as dust, is present. This static electricity is generated frequently around grinding, cleaning and other types of machines, as well as by the friction of pulleys and belts. The sparks produced may ignite the dust in suspension or other inflammable material about the machinery and initiate a primary explosion or fire which may develop or spread into one of large proportions. Later chapters will discuss explosions and fires which have been started in industrial plants, threshing machines and cotton gins from this source, and the subject of static electricity as a cause of explosions has been deemed of sufficient importance to demand a separate chapter. Consequently it will suffice at this point to mention the fact that it is a cause which must be seriously considered, especially where the more inflammable and the finer and dryer dusts are present.

It will be enough to state that discharges of static electricity will ignite dust clouds under certain conditions and cause explosions so that a hazard exists wherever static electricity may be generated in the presence of a dust cloud. The best way to prevent this hazard and resulting explosions is to remove or neutralize the static electricity as fast as it is generated so that a discharge will not occur. One method which has been suggested to remove the charge, humidifying the atmos-

phere, is based on the fact that static electricity accumulates in largest quantities in a dry atmosphere, and that the charge easily dissipates itself into a humid atmosphere. Although this method has some advantages, it is not recommended for use where dust clouds are present in industrial plants.

If a direct connection is made between the ground and the portion of the machinery where static electricity is generated, the charge will be conducted away to the ground as fast as it is generated. However, a thoroughly good ground connection must be made to be effective, and

Damage caused by an explosion in an elevator at Weehawken, N. J. The explosion apparently originated in a steel storage bin, blew off the tile and cement top and propagated throughout the cupolas, blowing out the tile walls and causing the damage shown.

it is advisable to make at least three so that if one should become inoperative, the other connections would take care of the charge. (For methods of grounding, see chapter VII.) Friction between some materials creates a positive charge while between others it creates a negative charge. Advantage of this fact is taken in preventing static electrical charges from accumulating on balloons and aeroplanes. They are coated with certain preparations so that both charges are generated in equal quantities and neutralize each other. The same principle has been applied in making some belt dressings. It is also possible to neutralize static electricity as rapidly as it is generated by the use of a high frequency electrical current which with proper equipment will charge the air with

negative and positive electricity, and so neutralize either charge as it is generated.

Just what method of removing the static electrical charge is decided upon depends altogether upon local conditions but, under any circumstances, it should be removed wherever it is possible for a dust cloud to form and a discharge to occur.

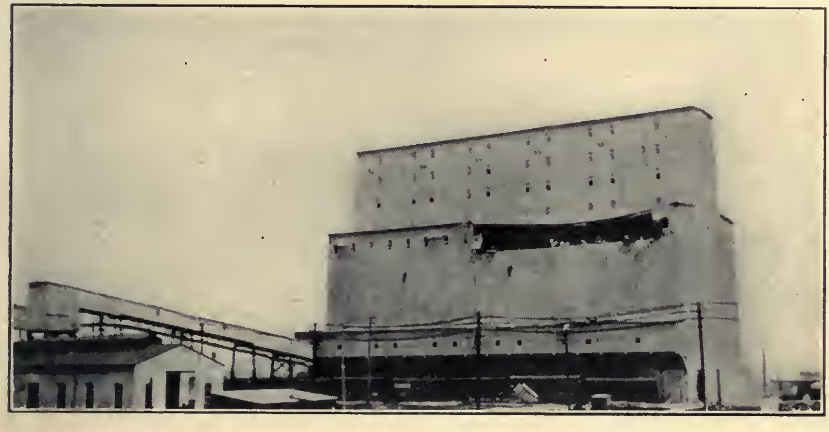
7. *Choke-Ups and Friction in Elevators.*—Many explosions, particularly in grain elevators, have been caused by choke-ups in the leg and by friction developed in the elevator, usually as a result of misalignment of the belt. When a choke-up occurs the belt stops but the pulley in the head continues to run. The friction between the belt and the pulley produces intense heat and the belt will begin to burn. This may be only a coal at first but it may burst into a flame. In either case the ever-present dust in the leg becomes ignited and an explosion results. Or, as in the case of the explosion in the government elevator at Port Colborne, Ontario, it may be that the dust has settled by the time sufficient heat has been developed to ignite it. In that event the belt will continue to burn, as it did in this case, until it becomes so weakened that it will separate and fall down the legs of the elevator. The dust is stirred up by the falling belt and ignited by the coals or flame at the burning ends of the belt. At Port Colborne this thing probably would not have happened if the choke had occurred at any other time than just before the noon hour for someone would have been near the elevator head and would have noticed the smoldering of the belt in time to have extinguished it before the belt was sufficiently weakened to separate, as it was an hour and a quarter after the choke-up occurred before the belt parted and the explosion happened. In a somewhat similar explosion in an elevator in Baltimore, one of the elevators became choked. Before the choke was located, sufficient friction had developed so that the belt took fire, weakened and broke, stirring up a dust cloud which was ignited by the belt. A disastrous explosion resulted.

Even though a warning may be given, it sometimes happens that it is not heeded by the employees. This was the case in an explosion which occurred in an elevator in Brooklyn, N. Y. Men working on the next-to-the-top floor noticed the odor of burning rubber. They decided to wait until they had finished running the rest of the bin on which they were working. They finished it and then went to the top floor to locate the trouble. The smoke seemed to come out of one of the elevators and on opening the hand hole it was found that the belt was way over on one side. The men then started downstairs; one of them had gone but a few steps when an explosion occurred in this elevator, blowing off the head and stirring up and igniting the dust in the tower, causing the secondary and more disastrous explosion. As a result of this and the fire which followed, the entire elevator with over 800,000 bushels of grain was destroyed.

This danger exists in the operation of all elevators. Therefore, great care should be exercised at all times to see that no friction can occur, and that in case of a choke-up the driving force will be shut off as soon as

possible, preferably automatically, and the belt examined thoroughly to see that it has not become heated before starting again.

In the operation of elevators it is not uncommon to have the belt become overloaded. This may be caused by overfeeding of the elevator, or, as it is often expressed, to back-legging. That is, the material is not carried over into the discharge spout but falls down the back leg where it has to be elevated again. It has the same effect as overfeeding. If this overload is not noticed and the excess removed the belt will begin to slip. It will then slow up and finally stop. But the head pulley will continue to run and create such friction on the belt that it may soon take fire unless the pulley is stopped or the choke-up relieved so that the belt can start. If the belt has begun to smolder or has taken fire an explosion may occur as soon as a dust cloud reaches the coals or flame. Choke-ups are bound to occur occasionally in any elevator and they introduce an imminent hazard. To relieve the choke instantly or to stop the elevator completely until it has been cleared enough to start easily is imperative. This means that constant attention must be given to the elevators, or that there must be some automatic method of shutting off the power so that the head pulley is stopped as soon as the belt stops.



An explosion in a grain elevator in Galveston, Tex., on March 30, 1914, in which there was comparatively no fire damage. The explosion traveled over the top of the bins and blew out the sides of the structure.

There is considerable objection among elevator operators to any device which will automatically shut off the power in case of a choke-up because it is thought that time and work can be saved by making the elevator "plow through" the choke. This may be true but it is done at great risk. However, the objection is so strong that the problem must be approached from the other direction, that is, by relieving the choke so that the elevator can handle the load and get back to normal operation.

A method having considerable merit is the installation of a signaling device which will automatically notify the operator when the belt begins to slow up, indicating the start of a choke-up. One simple contrivance consists of a piece of leather put into the front casing of the front-leg in such a way that the buckets strike one end of it in passing and cause a vibrating of the end outside of the casing, the rate of vibration indicating the speed of the belt. Another device rings a bell and turns on a red light when the belt begins to slow up. Although more elaborate and expensive, the latter method is much more effective as it will call the attention of the operator to the impending trouble and will also allow him time to do something else besides watch the elevators. However, a device of this sort must be installed in such a manner that it not only calls attention to the fact that trouble is starting but it must indicate its exact location.

One large elevator has an installation which seems to be effective in preventing choke-ups in its elevators. Connected to the shaft of the idler pulley is a device which prevents the starting of the conveyor belt carrying material to the boot of the elevator until the elevator is running at normal speed. When, in slowing up, the elevator belt reaches a certain speed the power driving the conveyor belt is shut off, stopping the belt, and a signal is given to the operator indicating the location of the trouble. He can then start the conveyor after the elevator has cleared itself and is running normally. An installation of this kind is one of the best safeguards against choke-ups known to the authors.

To prevent choke-ups caused when the elevator discharge spout becomes filled and the material falls down the back leg, different types of non-chokeable elevators have been designed by elevator and mill furnishing companies. The elevator of the type shown in Fig. 15 is a combination of the Hall non-chokeable boot and the Gump non-chokeable turn-head. It will be noticed that it is not essentially different from the usual type of elevator, except that it has two discharge spouts. As a usual thing the material is discharged through the lower spout, but when this becomes filled the other spout will return it to the elevator boot.

Besides guarding against choke-ups in elevators, care must be taken so that friction does not occur when the belt gets out of alignment and rides on one side of the head pulley. In such cases the friction between the belt and the casing of the elevator head may cause an explosion. As many disastrous explosions have started in elevators, every precaution should be taken to prevent choke-ups and friction and all other possible sources of ignition.

SUMMARY.

A number of definite causes of dust explosions and methods of eliminating the sources of ignition have been established. These have been discussed briefly, and the causes may be summarized as follows:

(1) Smoking and carrying of matches in the plants.

(2) Use of open flames and lights, such as torches, gas lights, lanterns, candles, etc.

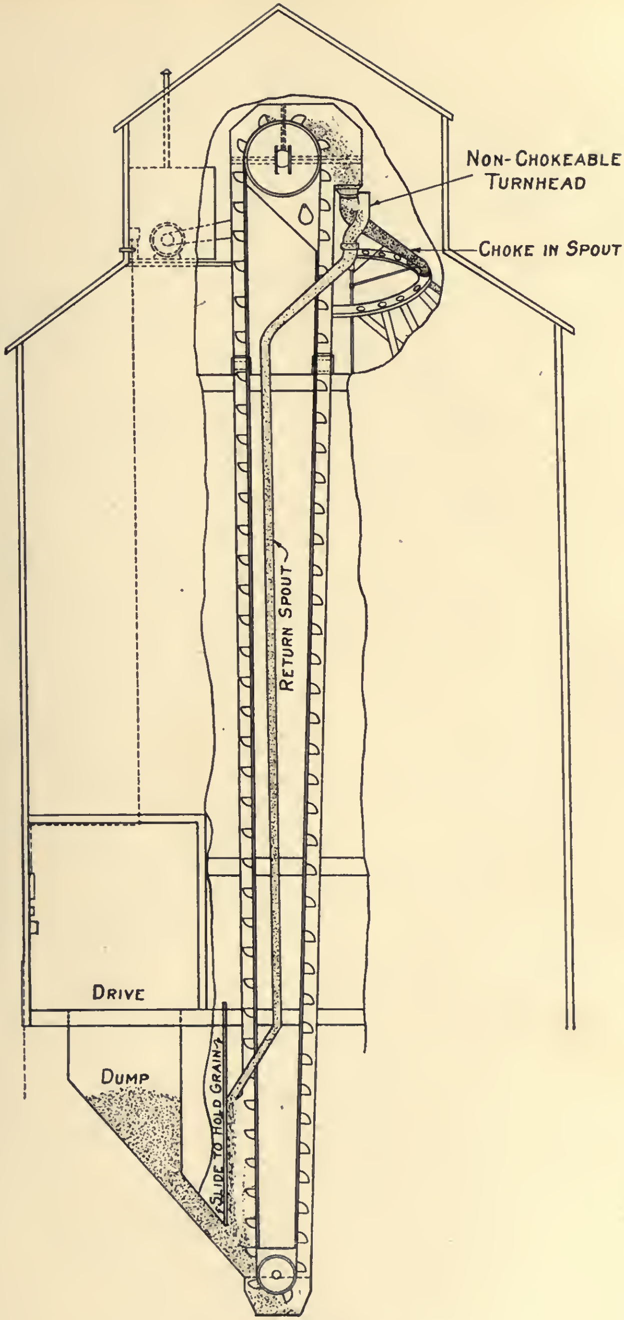


Fig. 15.
Non-chokeable Elevator Head.

(3) Small-scale fires caused by general sources of ignition which may come in contact with a cloud of dust in the plant.

(4) Electrical causes, such as sparks from motors, fuses, switches, short circuits, the breaking of incandescent lights and the firing of dust accumulated on the lamps.

(5) Sparks struck by foreign material going through the grinding machine.

(6) Static electrical discharge.

(7) Choke-ups and friction in elevators.

CHAPTER IV.

PREVENTION OF EXPLOSIONS BY CONTROL OF EXPLOSIVE MIXTURES.

As the requirements for an explosion are a proper mixture of dust and air and a source of heat sufficient to ignite the dust, it follows that to prevent an explosion it is necessary to remove all possible sources of ignition or to prevent a proper mixture of the dust and air. In many cases either may be very hard to accomplish entirely, as, for instance, in a grinding machine where it would be necessary to find other means of prevention. The dust can not be removed or kept down and the spark may get in, but there is still another factor which may be altered. That is the air. It is the oxygen of the air which unites with the dust in the explosion. Consequently, if it were possible to remove or sufficiently reduce the oxygen of the air an explosion could not occur even though the usual percentage of dust to form an explosive mixture were in suspension and a source of ignition were present.

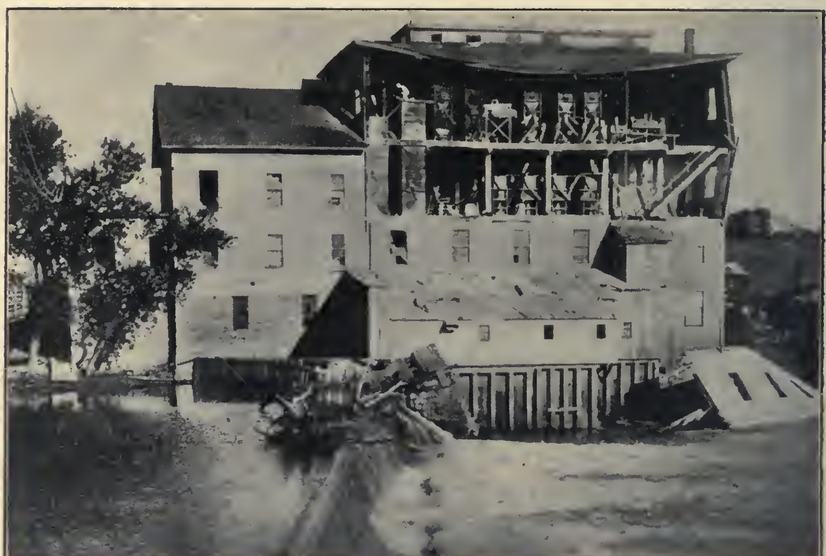
Explosive Dust and Air Mixtures.

Though every possible known precaution has been taken to prevent the causes of explosions, the unexpected may happen and the preventive measures may be ineffective. The spark or flame at the most unexpected place causes an explosion if a dust cloud is also present. The formation of the dust cloud must be prevented or it must be made of such proportions that it is not explosive. It would not be practicable to try to maintain a cloud so dense that the explosive limits were exceeded, for when starting up and shutting down the plant, or at times when the flow was not normal, the percentage would change and pass through the explosive limits. At such times the spark or flame might occur and an explosion result. It may not be possible in certain manufacturing processes to keep the cloud light enough to be under the explosive limits, as, for instance, in grinding machines, but it is possible to keep the dust out of the plant, and to decrease the amount of dust in suspension at the various points where it is created.

Many operators say that their plants are clean, or as clean as it is possible to keep them, when it is not possible in some parts to see more than a few feet on account of the dust in the air, or several inches of dust have been allowed to settle everywhere. On the other hand, plants

carrying on the same business and using the same methods of manufacturing or handling products will have no dust in the air and there will be no visible accumulations about the plant. This difference is due entirely to difference in equipment and in the ideas of the operators. With machinery properly operated and tightly inclosed so that the dust cannot get out into the atmosphere and reasonable care on the part of the operators it is possible to maintain a clean plant.

Wherever dust is created in a manufacturing plant a small amount of it will get out into the atmosphere of the mill and gather on floors,



An explosion of flour dust in a mill in Beatrice, Neb., on September 22, 1914, believed to have been caused by the striking of a match in a flour bin.

walls and ledges in spite of every precaution. If it is allowed to accumulate even in small quantities a hazard is present, for the primary explosion may start at a point where the dust is made and get out into the surrounding atmosphere, stirring up the accumulated dust and propagating through it. If there is no accumulation of dust and the plant is perfectly clean the explosion cannot propagate and the plant will not be destroyed.

Several methods for keeping dust out of plants are in use and others have been suggested. If it were possible to remove and collect the dust from the points at which it is created, much could be accomplished in keeping plants clean and in preventing the spread of explosions. For instance, in the operation of a grain elevator, dust is thrown into the atmosphere wherever there is a throw of the grain. If a suction could be placed at such places, to remove and collect the dust, the elevator could be kept much cleaner, and the operating conditions would be greatly

improved. In fact, the installation of some type of aspirating system to remove the dust at its source is of the greatest importance. It will not only help to keep it out of the atmosphere of the plant, but it will decrease the percentage of dust in the atmosphere at the point where it is created, thereby weakening the mixture of dust and air so that, if properly installed and operated, it will prevent an explosion from starting at that point.

Considerable objection has been offered to such an installation in a grain elevator, especially at points ahead of the scales, because it is thought that the suction would remove dust from the grain and decrease the weight, and also that it could be subjected to considerable abuse. Anything is subject to possible abuse, but regulations for controlling the amount of suction could be enforced and the system operated under proper supervision. It is not advocated that a suction sufficiently strong to remove all the dirt from the grain be installed, although it would have many advantages, but it should be strong enough to draw away the light dust which is raised and which would naturally float into the air. Such systems have been installed in some places but the operators have not been allowed to use them on account of the above objections. The benefits to be derived from a properly installed and operated aspirator system far outweigh the objections, as it insures better working conditions and a cleaner, safer plant.

In most industrial plants push brooms are generally used for removing the dust collected on floors, beams, etc. The dust is swept up into piles and either removed by hand or brought up to a suction sweep, which is an opening through which it is carried by suction to a collector. It is not possible to sweep a plant perfectly clean, for the dust which is always raised floats in the air and finally resettles on places already swept. Careful sweeping does not stir up much dust but the usual sweeper is none too careful.

This objection, together with the efficiency of vacuum sweepers and cleaners, has been largely responsible for substitution of these for the broom in the home. The development of an efficient vacuum sweeping or cleaning system for industrial plants would fill just as big a need and desire for cleanliness in industry as it has in the home. Some progress has been made along this line, but up to the present time, so far as is known to the authors, an altogether efficient, practical and durable vacuum system has not been developed or installed in any industrial plant.

Dust collection and removal is one of the most important phases of explosion prevention, for explosions cannot occur nor can they propagate through a plant where there is no dust to be stirred up to feed the flame of the explosion. A full discussion of this subject has been reserved for a later chapter where the various methods of collection will be treated separately.

Inert Gases.

It has been stated in a previous chapter that there are explosive limits of dusts as of gases, or, in other words, that it is possible to have too

weak as well as too strong a mixture of dust and air, and that the most explosive mixture lies between these two limits. While this statement is altogether true when applied to air as such, in reality it is the proportion of dust or gas to the oxygen of the air which controls the explosive limits. This can easily be seen in the method which the Bureau of Mines (page 22) uses to determine the relative inflammability of coal dust. Oxygen is used to insert the dust, thereby increasing the inflammability of the samples. As an increase in the amount of oxygen means that the explosive limits of the dust and gas mixture would be increased, so a decrease of the amount of oxygen means that a point would be reached where an explosion could not be *initiated*.

It is not possible to decrease the oxygen of the air in an industrial plant nor is it practical from an operating standpoint. However, there are certain machines and equipment in most plants in which it should be possible to change the composition of the atmosphere and so to maintain it that even though dust and a spark or flame should be present at the same time, a dust explosion could not occur. A series of laboratory determinations was made to establish the per cent to which it would be necessary to decrease the oxygen content of the air before an explosion was impossible. For this work the laboratory apparatus, already described on page 25, used for determining the relative inflammability of various dusts, was adapted. The globe was filled with atmosphere containing various percentages of oxygen, carbon dioxide and nitrogen, the nitrogen always being 79 per cent and the mixture of carbon dioxide and oxygen making up the other 21 per cent. Several dusts were tested and the re-

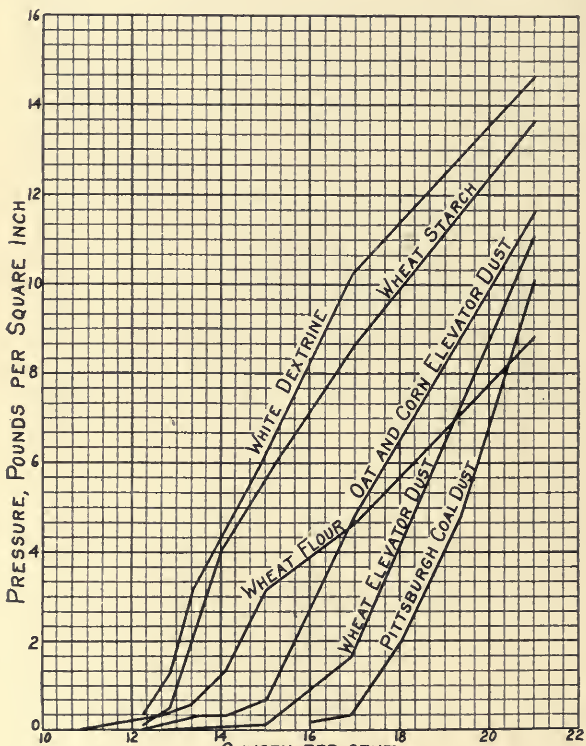


Fig. 16.

Relation of Inflammability to Amount of Oxygen Present.

sults are shown as curves in Figure 16. It will be noted that in each case as the oxygen content of the atmosphere was decreased the pressure created by the ignition of the dusts also decreased. In the case of the Pittsburgh coal dust, when the oxygen content of the atmosphere was reduced from 21 to 16 per cent only about 1/10 of a pound per square inch pressure was registered in the slight ignition of the dust. With elevator dusts, a very low pressure was generated when the oxygen content of the atmosphere was reduced to 14 per cent, while in the case of dextrine and starch it was necessary to reduce the oxygen to 12 per cent before ignitions could not be obtained.

As it is always possible to obtain finer adjustment and more accurate results in laboratory tests than in actual working conditions, arrangements were made to conduct large-scale experiments at an industrial plant. In the possible adaptation of this method to prevent explosions, one of the first considerations would have to be the source of this air deficient in oxygen, or so-called inert gas. Most plants have some power system and usually one or more boilers. The stack gases from efficiently operated boilers should not contain more than 8 to 10 per cent of oxygen and it has been found in some cases that the percentage is much lower. As there would be objection to the use of these flue gases in the manufacture of food products, since they contain impurities such as sooty material and sulphur dioxide, it was necessary to test out different methods of purifying this gas before its use could be recommended. After several trials it was found that an ordinary coke scrubber with a spray of water running in counter-current down through the scrubber against the upflowing gases was very efficient in removing the impurities. As high as 95 per cent of the sulphur dioxide could be removed easily and all of the soot was taken out.

While it would be proposed to use inert gases primarily in grinding systems, it was hardly practical to operate such a unit in an experimental way because of the large quantity of material which would be needed. Consequently a small screening and conveying unit, in which dust was thrown into the atmosphere at almost every point, was built, but on a site some distance from the plant because of the danger of making such experiments in a mill during normal operation. This unit consisted of a full-sized cylindrical reel covered with copper gauze and discharging into the screw conveyor which in turn discharged into a single-leg elevator. This carried the material to another screw conveyor which discharged the product into a small hopper that fitted into the reel. As, normally, a reel casing is not very tight, it was necessary to cover the casing and make the entire system as nearly gas tight as possible before tests were started. The distance between the unit and the boilers prevented the use of the stack gases in these tests; besides, gas mixtures of much lower oxygen content were desired. Consequently a small furnace was set up near the equipment, in which it was possible to regulate the valves to obtain any desired efficiency in combustion and consequently any desired percentage of oxygen and carbon dioxide in the stack gases. These gases were then led into the boot of the elevator and the top of the reel housing.

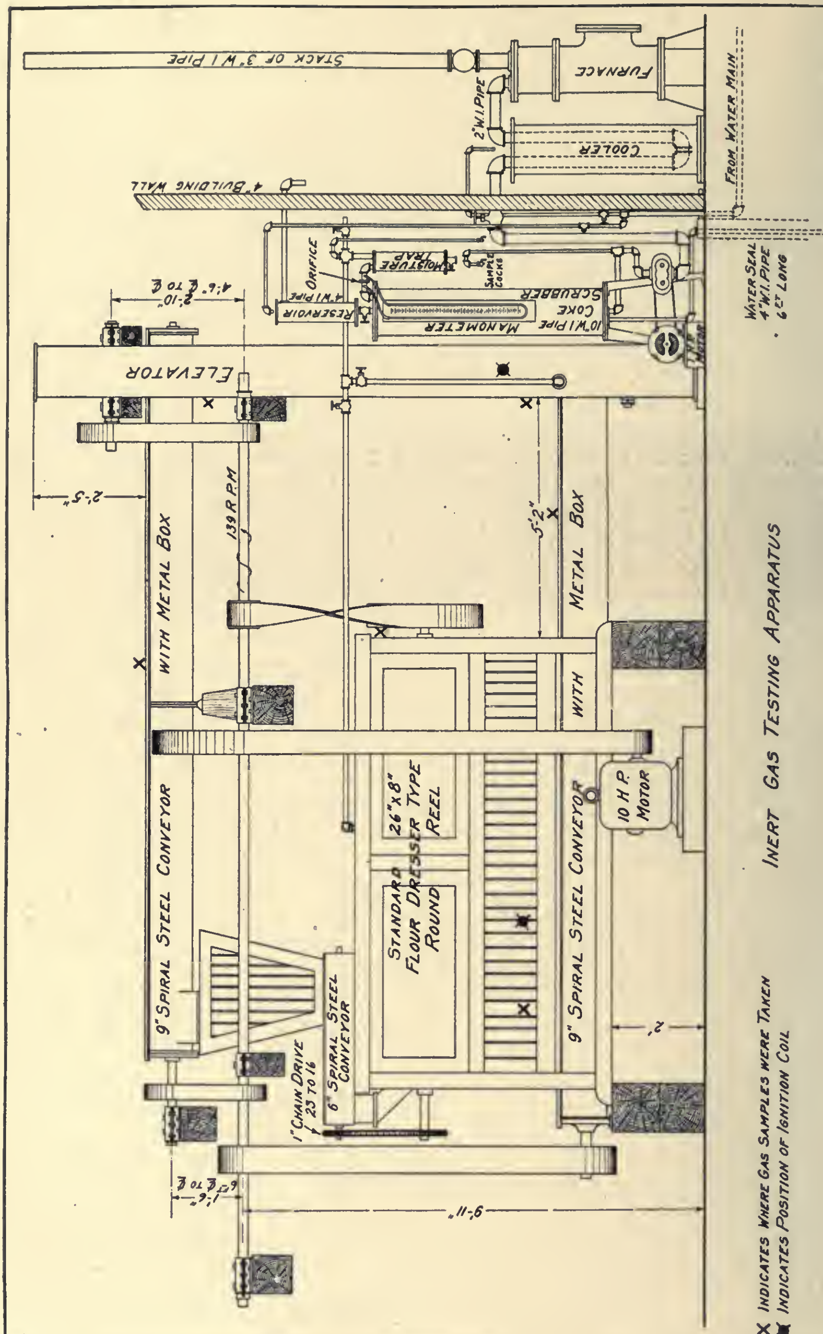

STACK OF 3" W.I. PIPE
FURNACE
COOLER
2" W.I. PIPE
FROM WATER MAIN
4" BUILDING WALL
ORIFICE
MOISTURE TRAP
SAMPLE COCKS
4" W.I. PIPE
RESERVOIR
MANOMETER
SCRUBBER
COKE
10" W.I. PIPE
WATER SEAL 4" W.I. PIPE 6 FT LONG
ELEVATOR
4'-6" ℄ TO ℄
2'-10"
2'-5"
139 R.P.M.
5'-2"
9" SPIRAL STEEL CONVEYOR WITH METAL BOX
9" SPIRAL STEEL CONVEYOR WITH METAL BOX
STANDARD 26"x8" FLOUR DRESSER TYPE ROUND REEL
10 H.P. MOTOR
6" SPIRAL STEEL CONVEYOR
1" CHAIN DRIVE 23 TO 16
2'
6 FT ℄ TO ℄
1'-6"
11'-6"
INERT GAS TESTING APPARATUS
X INDICATES WHERE GAS SAMPLES WERE TAKEN
INDICATES POSITION OF IGNITION COIL

Fig. 17.

As a source of ignition, heating coils made from nichrome wire were mounted in a small asbestos-lined metal box with the sides left open. When it was found that the product accumulated on the coils the sides were closely covered with paper pasted near the coils, which burned off when the current was turned on and exposed the hot coils to the dust in the atmosphere. In conducting the tests the apparatus was started and the gases were forced into the system until the desired mixture was obtained. The current was immediately turned on the ignitor and if the oxygen content was sufficiently high an explosion always resulted. It will be noted in Figure 17, that the ignition coil was placed sometimes under the reel and sometimes in the elevator. When in the elevator, it was placed a short distance above the lower pulley, at a point where there was a heavy dust cloud. A glass was placed on the outside of the elevator so that the behavior of the dust around the coil could be observed. In all tests dextrine or starch or mixtures of them were used.

It was found in every case that when the oxygen content was more than 15 per cent an explosion would be obtained in the system, but when it was between 15 and 17 per cent the explosion was not very intense—at least sufficient pressure was not developed to damage the system in any way. In all tests where less than 14 per cent of oxygen was present no ignition was obtainable, but when the oxygen content was about 14.6 per cent a tonguing-out of the flame from the igniting coil was noticed, but there was no propagation of an explosion. As a result of these tests it is believed that the maintaining of an atmosphere of less than 14 per cent oxygen in any grinding or grain-handling system will prevent explosions. However, it is recommended as a margin of safety that an atmosphere of less than 12 per cent oxygen be maintained.

In Figure 18 is shown a sketch of a possible installation for the use of inert gas in a grinding system. It will be noted that the gas is drawn from the stack, passed through a scrubber, blower and moisture traps, then through an orifice box or some other device for measuring the flow of gases, and thence to the various parts of the equipment. The gas is conducted into a grinder along with the grain, then into the various conveyors to the elevator and bin, and the latter is vented to the outside air. It is probable that in an ordinary mill there would be sufficient ventilation so that the amount of gas necessary to maintain an inert atmosphere could be allowed to escape into the air of the mill without affecting its purity enough to harm the employees. With such a system installed it should first be determined that the stack gases are always uniform, and that they never contain more than 12 per cent of oxygen. While the large-scale tests have shown that explosions will not start in atmospheres containing less than 14 per cent of oxygen, a margin of 2 per cent is none too much for safety. In order that uniformity may be maintained, and that a record may be kept to show the amount of oxygen in the system, the installation of a carbon dioxide recording apparatus is advisable. While this will not give the oxygen percentage direct, it may be obtained by difference, as the stack gases always contain about 20 per cent of the mixture of carbon dioxide and oxygen.

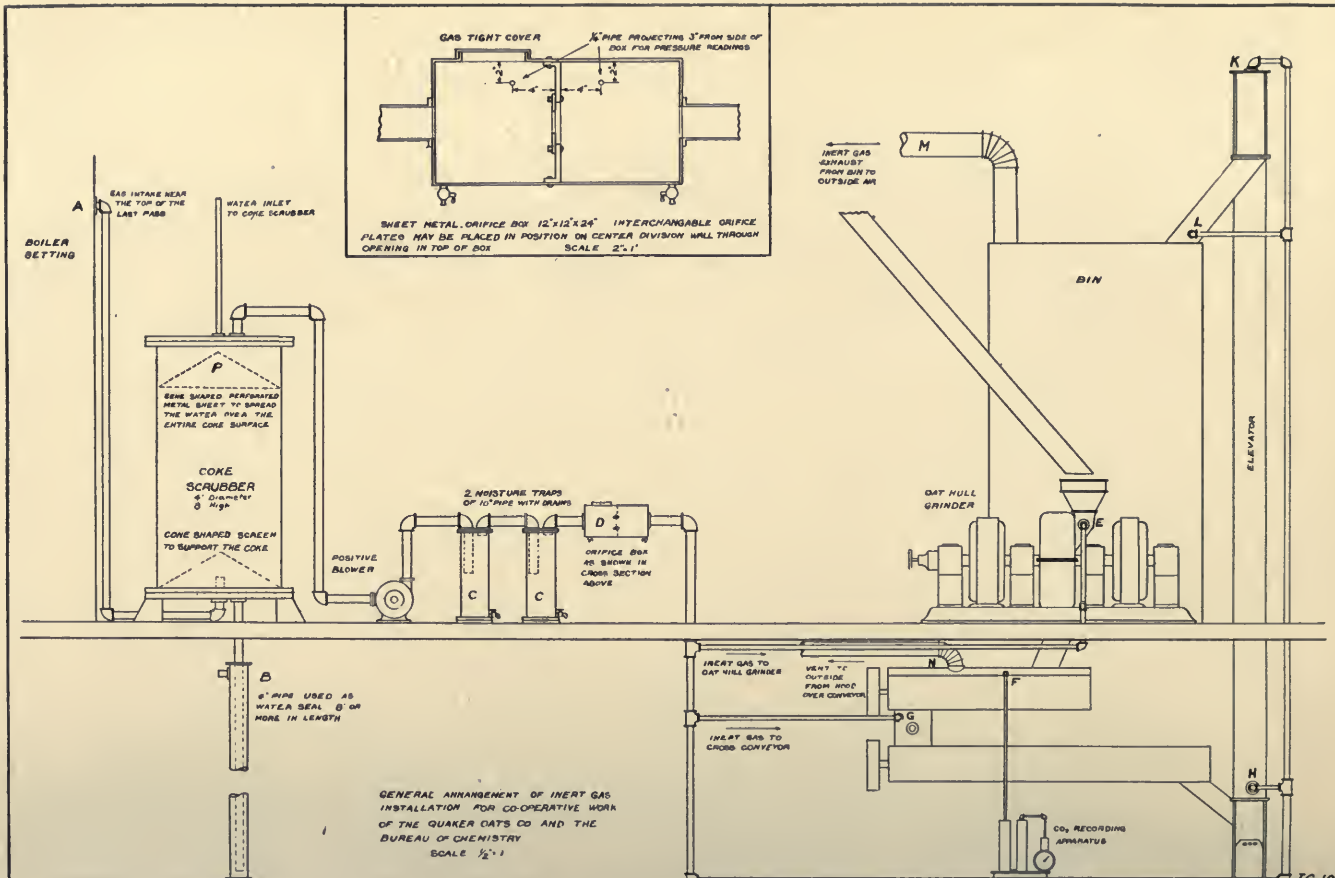


Fig. 18.—Inert Gas Installation in a Grinding System.

One objection which has been raised to the installation of such a system is the presence of carbon monoxide in the flue gases. According to the tests which have been made thus far, however, the authors do not believe that this gas would get into the atmosphere of the mill in sufficient quantity to trouble the employees in any way. With 10 to 12 per cent of oxygen remaining in the stack gases, the percentage of carbon monoxide is very low, usually considerably less than one-half of one per cent, and with the comparatively small amount of the stack gases that would be used throughout the system the accumulation of this gas in the atmosphere would be almost negligible.

Another objection which has been raised to the use of this method of prevention is its possible effect upon edible products such as flour, etc. To determine any effect of impurities upon these materials, washed and unwashed flue gases were passed into the system. With the washed gases no effect was shown upon dextrine or starch. A more thorough test was made with unbleached flour bought in the open market. This was kept in agitation in a revolving barrel with the stack gases passing through the barrel for varying lengths of time. At half-hour periods the tumbling of the barrel was stopped, and a sample of the flour was removed. The operation was then continued, each time increasing the impurities in the gas and gradually allowing those absorbed by the flour to accumulate. Results of the tests are shown in Table XIX.

It will be observed that in no case was there any bleaching effect on any of the flour samples, showing that in the most impure flue gases there was not sufficient sulphur dioxide present. However, if the gases were not well washed the flour absorbed some of the impurities and took on a tarry odor which became more pronounced as the impurities in the gas were increased, until in the last samples, where the gas was not washed at all, it was very strong. Traces of soot were also found in the last sample.

It is evident that if there was arsenic in the gases, it was not present in quantities large enough to affect the purity of the flour. The amount of sulphur dioxide absorbed was also very small, being 0.0025 of one per cent in the last and most impure sample and not over 0.0013 of one per cent in any of the other samples. This amount is not sufficient to affect the flour as a food product.

In further demonstration of the effect of flue gases on flour, baking tests were made with seven of the samples which were analyzed. Plates III and IV show the loaves which were made from these samples compared with a standard untreated sample. In plate No. III, the standard loaf is unnumbered. In plate No. IV the loaf shown on the left was made from sample No. 10 while the standard is on the right. A study of these photographs shows no marked difference in the size and texture of the loaves, indicating that the gases did not greatly affect the flour. It may be noted, however, that there is a difference in color in the last samples, due to the presence of soot or tarry impurities from the gases.

TABLE XIX.
TREATING FLOUR WITH FLUE GASES.

Sample No.	Time of Gas flow.	Gas flow per minute.	Coal used.	SO_2 in gas as entered.	Washing notes.	Combustion notes.	Moisture at 100° in Vacuo.	Ash.	SO_2.	Arsenic.	Odor.
	Minutes.	Cubic feet.		Per cent.			Per cent.	Per cent.	Per cent.	Parts per million.	
1 Control sample	....	....	....	....	....	....	8.72	0.42	0.0000	None.	....
2	30	8.6	Soft	0.00032	Very good	Complete	8.73	0.40	0.0000	None	Normal.
						Incomplete					
3	30	8.6	Soft	0.010	Good	Fresh coal bed	8.71	0.41	0.0006	—.1	Normal.
4	30	8.6	Soft	0.022	Slight	Fresh coal bed	8.75	0.43	0.0006	—.1	Coal tar odor developed.
5	30	8.6	Soft	0.020	Slight	Fresh coal bed	8.70	0.43	0.0006	None	Distinct coal tar odor.
6	30	9.4	Soft	0.025	Slight	Fresh coal bed	8.67	0.42	0.0006	—.2	Distinct coal tar odor.
	30	9.4	Soft	0.009	Slight	Nearly complete combustion.					
				Av.0.017							
7	30	9.4	Soft	0.013	Slight	Incomplete. Fresh coal bed	8.66	0.43	0.0010	None	Distinct coal tar odor.
8	30	9.4	Hard	0.056	No washing	Fresh coal bed	....	....	....	....	....
				0.028	No washing	No coal added	....	....	....	....	....
				0.019	No washing	Little coal added	8.68	0.43	0.0013	.2	Distinct coal tar odor.
				Av.0.034							
9	30	9.4	Hard	0.026	No washing	Fresh fire	8.65	0.44	0.001	Insufficient Sample	Strong coal tar odor.
				0.037	No washing	More coal added ...	....	....	....	....	
				Av.0.032							
10	30	9.4	Soft	0.047	No washing	Fresh coal maintained on grate	8.61	0.56	0.0025	.2	Very strong coal tar odor

Note. The color was normal and the bleaching effect was not noted in Samples Nos. 2 to 9 inclusive, while Sample No. 10 showed traces of soot.

Expansion tests were also made on these samples. All of them up to 5 stood up as well as the standard, but Nos. 6, 7, 8 and 10 went down in the inverse order, No. 10 going down first. This would indicate that the gluten was affected by the gases, but not seriously so until after their presence was made noticeable by the color and odor of the flour.

As a result of these tests and analyses it appears that if the gas is washed so as to remove all of the soot and tarry matter and most of the sulphur dioxide it will not affect the purity of the food products with which it comes in contact.

It is fully realized that such a system has certain limits and that there are certain parts of a plant in which it could not be utilized, as it might not be possible to maintain an inert atmosphere, as, for instance, in the dust-collecting system. However, it should be possible to utilize inert gas in preventing the propagation of an explosion which might be started either inside or outside of the system. To determine the possibility of doing this, tests were made, using a gallery of galvanized iron 100 feet long and 2 feet in diameter. This gallery was filled with dust from hoppers by means of air jets, and then the dust was ignited at one end by burning waste. A tank was placed about 60 feet from the igniting end of the gallery and from it two pipes ran into the opposite sides of the gallery. The tank was equipped with a quick-relief valve which was held closed by a trigger device connected with a tight wire running through and near the top of the gallery. This wire carried fusible links, which when fused by the heat of the explosion would cause the sudden opening of the relief valve and the escaping of the inert gas[1] into the gallery. In all cases when a link 40 feet or more ahead of the gallery was fused the gas escaped into the collector in sufficient time to be ahead of the flame and to smother it. Many tests were made with this system and it was possible to reproduce these results whenever desired.

It is believed, as a result of these two series of tests, that the use of inert gas in preventing explosions and also in stopping their propagation is altogether feasible.

Prevention of Explosion Propagation.

Reference has already been made to the fact that it is not the primary explosion which causes the greatest destruction in industrial plants, but it is the secondary explosion which propagates through the dust which has accumulated at various points, and that this secondary explosion may be prevented by keeping the plant clean. However, there are certain places in industrial plants where an initial explosion may propagate through the normal channels of operation to a large container, as a bin, and an explosion of large proportions occur that will wreck a substantial part of the plant. A number of means of prevention of this propagation have been suggested. Most of these apply to installations in connection with grinding equipment, as a great many explosions start in grinding machines.

The first thing to be considered in the installation of all equipment

[1] Carbon dioxide was used instead of stack gases.

PLATE III.—Photographs of Bread made to show effects of Flue Gases on Flour.

which is to be used in grinding or pulverizing carbonaceous material is its location in the plant. It should be placed in a separate building or in a section of a building which is entirely detached from the packing, storage, or shipping rooms, so that an explosion which starts in the grinding equipment could not propagate throughout the entire plant. Suggestions have already been made for the installation of equipment to remove all foreign materials and to clean thoroughly the product going into the mill so as to minimize as much as possible the chance for explosions from such causes. Reference has also been made to the grounding of the machines so that all static electrical charges will be removed. Even with

PLATE IV.
Photographs of Bread made to show effects of Flue Gases on Flour.

these precautions, explosions may start in the grinding machines and steps should be taken to prevent their propagating. Among the means of prevention may be considered revolving dampers, choke conveyors, vent pipes, relief valves and automatic releasing doors at various points in the system.

Some device which will at least help to stop the passage of the explosion through the conveying system should be placed close to the grinding machine. One device which has been tested is a so-called revolving or explosion-damper. Results have shown that the installation of one such damper in a system will stop the passage of a number of minor explosions and that two dampers in series will prevent the propagation of most explosions, although a few did get by the second damper. Another device, a so-called choke conveyor, is one in which a number of the flights have been removed at the discharge end so that the material being conveyed will fill up the conveyor and will feed out through the opening only by being crowded by the other material coming along behind it. This will also check the explosion. With either of these installations it is advisable to put a vent pipe between the grinding machine and the conveyor.

One suggested installation is shown in Figure 19 and another in Figure 20. It will be noticed in the first that two explosion dampers are installed, one directly under the attrition mill and one at the end of the

first short conveyor, and that there is a vent pipe to the outside air on the conveyor between these two dampers. In the second case, the revolving damper is placed ahead of the conveyor which has been made into a choke conveyor. A vent pipe is situated just in front of the revolving damper. It might be well to have another on the conveyor. These vent pipes should be as straight as possible so that there may be no obstruction to the passage of the explosion to the outside air. In case an explosion should get by these devices or in any way get into the conveying system, a relief

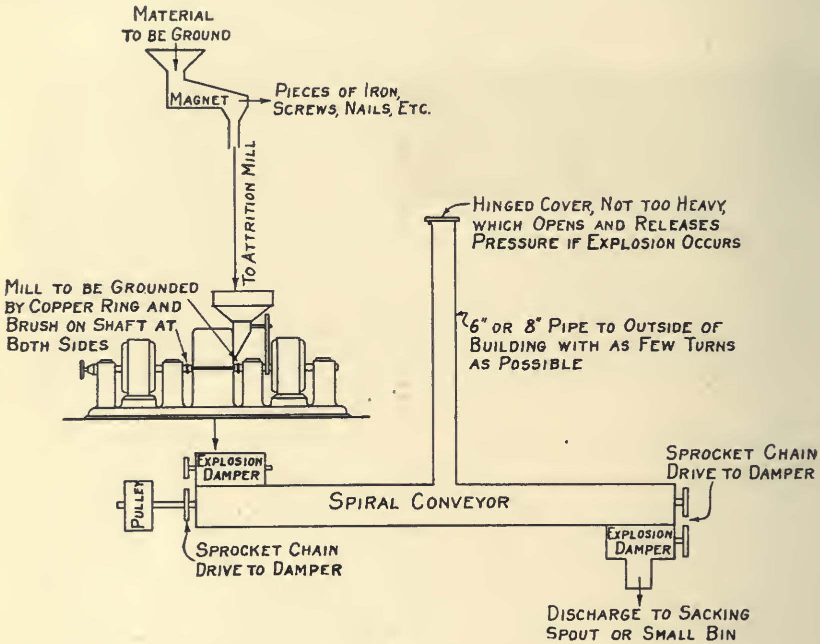


Fig. 19.
Use of Dampers and Vent Pipes in Grinding Systems.

valve or automatic releasing door as shown in Figure 21 will help to prevent the passage of the explosion further through the system. It will be noted that this consists of a hinged bottom on a section of the conveyor, which normally is held in place by ropes attached to fusible links within the conveyor. As the flame of an explosion reaches these fusible links they will separate, allowing the valve to open, and the explosion to vent itself into the surrounding atmosphere.

The usual method of operation in a feed mill is to convey the material to a fairly large bin, then to sack it as it may be convenient or necessary. When ground material is being run into an empty bin it is always filled with dust and an explosion of large proportions will result in case any flame or spark gets into it. Explosions of this sort could be decreased to a great extent if small sized bins were used to receive the material

from the grinding machine and the ground product were sacked as fast as made. An installation of this kind has been found not only practical, but valuable as an explosion and fire-preventive measure in several mills, and it is highly recommended.

A number of explosions which have started in various parts of industrial plants have been propagated to other sections of the plant through

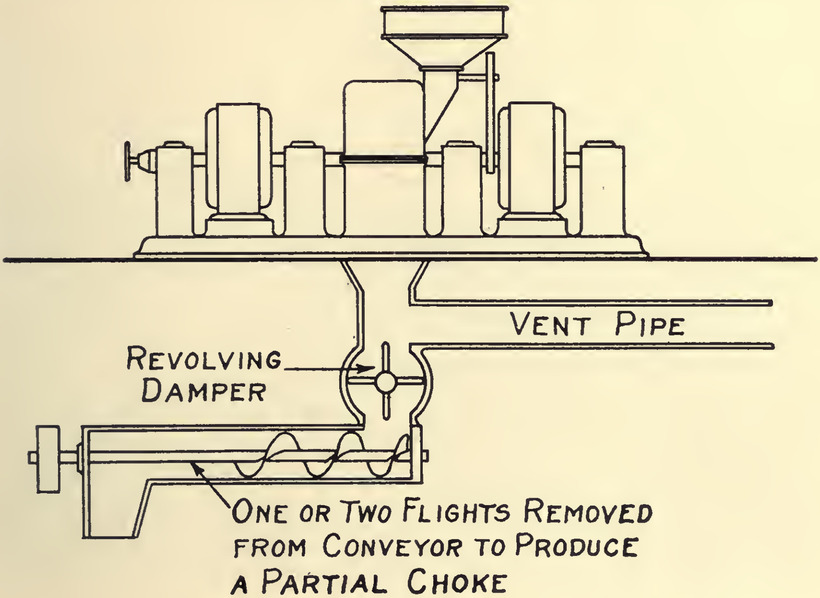


Fig. 20.
Use of Dampers and Vent Pipes in Grinding Systems.

dust-collecting systems. The use of inert gas has already been suggested as a possible means of prevention of the propagation of explosions through such systems. The German patents Nos. 218717 and 221637 describe a device with improvements for preventing the propagation of an explosion through such a system by the use of inert dust. A series of tests was made with a device[1], Figure 22, similar to that described in these patents, to determine its effectiveness.

[1] In the apparatus as constructed, pipe *a* in the drawing Figure 22 was 4 inches in diameter and box *b* was 14 inches long by 6 inches wide and 11 inches high. The box holding the inert dust was above valve *g* and was 6 feet from the box, *b*. The apparatus is also shown in photograph in Figure 23. It will be noticed that the box holding the inert dust is at the extreme right of the photograph. At the left is shown a small hopper connected to a Y in the pipe *a* at a distance of 10 feet from the box *b*. Valve *d* is held closed and valve *e* is held open by a weight attached to arms outside of the box. In Figure 22 it will be noticed that the clamp *h* is connected to the valve *d* but in the apparatus as tested this clamp was connected to valve *e* as it was thought that it would operate first and so open the valve *g* more quickly.

In making the tests a cloud of starch dust was blown through the apparatus, passing through and under valve *e* and on through the system. The dust was then ignited through an opening some distance back of this

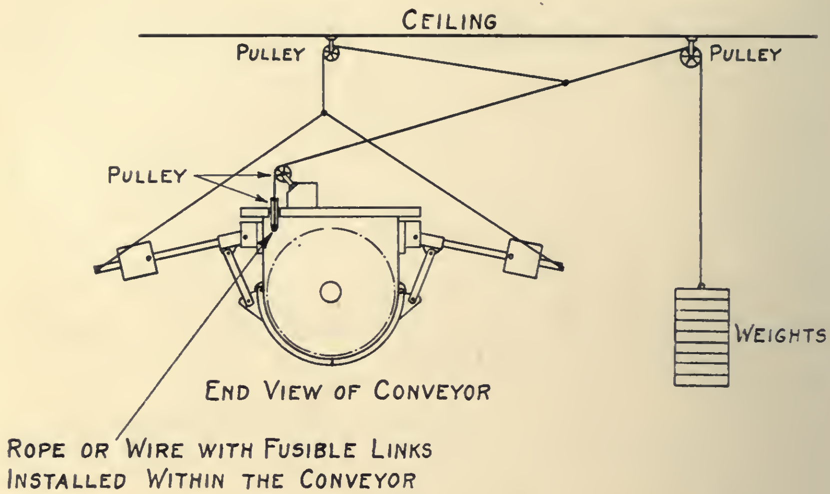


Fig. 21.
Device in Conveyor to Divert Contents in Case of Explosion or Fire.

valve and the explosion would propagate throughout the entire length of the system if connection was not made between the valve *e* and the clamp holding the valve under the chamber containing inert dust. Tests were

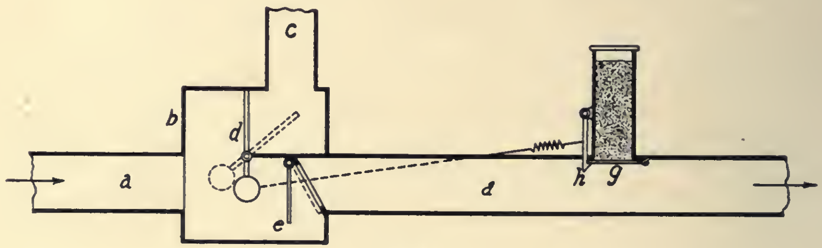


Fig. 22.
German Patent for Prevention of Propagation by Inert Dust.

made with inert dust in the chamber above valve *g* and also with this chamber empty but with the valve so weighted that it would drop quickly and close the pipe. Fully 50 tests were made in the two series and at no time did the flame go beyond the point closed by valve *g* provided inert dust was in the chamber above this valve. In a very few cases where no inert dust was used a small amount of flame passed on through the

system but most of the force of the explosion was diverted up into the chamber above valve g and through the opening c. So far as known there is no installation of this kind in this country, but the tests indicate the possible adaptation of inert dust, which has proved effective in preventing the propagation of explosions in mines, as a means of prevention of the propagation of explosions in conveyor systems in industrial plants.

Fig. 23.
German Patent for Deflecting Explosions.

Protective Regulations.

To protect employees against the hazards of dust explosions, certain regulations have been put into force by some of the states and by foreign governments. As early as 1914, the Industrial Board of the Department of Labor of New York State drew up one of the first preliminary codes of rules to be applied in the United States. About a year later a similar code was drawn up by the Industrial Board of the Pennsylvania Department of Labor and Industry. These two codes are almost identical and include regulations covering the following matters:

(1) New construction. (2) Openings from boiler and engine rooms. (3) Methods for heating and grain tempering. (4) Location of heating furnaces. (5) Location of electric generator sets. (6) Methods of illumination. (7) Providing belt conveyors with exhaust for dust removal. (8) Covers on grain garners and weighing hoppers. (9) Removal of foreign material from grain before entering grinding machines. (10) Elimination of dust or stive rooms. (11) Piping of exhaust sys-

View of Husted Milling Company's plant at Buffalo, N. Y., after explosion in which 33 workmen were killed and 80 injured. The explosion was very violent in nature, destroying the mill building and causing considerable damage to surrounding property. This disaster awakened considerable interest in the grain industry and resulted in special research investigations pertaining to the causes of these explosions and the development of effective methods of control and prevention.

tems. (12) Dust removal. (13) Carrying of matches, cigar lighters or devices for lighting. (14) Providing chemical extinguishers.

Regulations in Great Britain.

A series of disastrous dust explosions in the British Isles in 1911 resulted in the development of the following recommendations by H. M. Inspector of Factories for application in grain storage warehouses and other places where carbonaceous dust is generated in dangerous quantity, whether in manufacture, storage or transport. The first three of the recommendations apply to the construction of new premises:

(1) Rooms used for the purpose should not have other rooms above them, nor should they be adjacent to higher buildings which would be affected in the event of an explosion.

(2) The roof should be such as to offer little resistance in the event of an explosion.

(3) There should be no open beams, girders or other ledges, or projections on which dust could lodge.

(4) The floors, walls, machinery, appliances and any ledges, as above, should be cleansed from dust daily—preferably by a suction cleaner.

(5) Under-ground rooms are unsuitable for disintegrators or other grinding machinery.

(6) All grinding and mixing machines, hoppers, elevators, worms and conveyors (other than belt conveyors—see below) should be so constructed as to prevent the escape of dust, and preferably provided with exhaust draught. Belt conveyors should be provided with exhaust draught and adequate appliances for interception and removal of dust at the points where they are filled and discharged.

(7) Efficient electro-magnetic separators should be provided on the feed of each disintegrating or other grinding machine to arrest particles of iron or steel.

(8) No naked gas lights or electric arc lamps should be used in such rooms; and incandescent electric lamps should have outer dust-tight covers.

(9) In such rooms Regulation 27 of the Electricity Code (See definition which follows later in this report) requires special protection of conductors, switches, fuses and other electrical apparatus.

(10) No matches or smoking should be allowed.

(11) In connection with grinding and cleaning machinery, the use of a stive room is unnecessary and dangerous; more modern methods of intercepting the dust, such as cyclone collectors or bag filters should be substituted.

In connection with dust explosion prevention, H. M. Electrical Inspector of Factories submitted the following recommendations regarding use of electricity in grain storage warehouses and other places where carbonaceous dust is generated in dangerous quantity, whether in manufacture, storage, or transport:

"Regulation 27 of the Electricity Regulations should be regarded as applying in your case, this regulation requires:—

> 'All conductors and apparatus exposed to the weather, wet corrosion, inflammable surroundings or explosive atmosphere, or used in any process or for any special purpose other than for lighting or power, shall be so constructed or protected, and such special precautions shall be taken as may be necessary adequately to prevent danger in view of such exposure or use.'

"A dust cloud might be ignited through (1) the bursting of an incandescent lamp; (2) overheating of conductors or apparatus by (*a*) excess of current; (*b*) bad joints or connections; (3) inadequate protection of conductors and apparatus resulting in sparking; (4) arcing of apparatus needed for breaking circuits such as switches, circuit breakers, fuses and connectors for portable lamps.

"It is of course obvious that no lamps should be used except those of the vacuum type, and with regard to:

"(1) Such lamps should be enclosed in stout outer protecting glasses with rubber or other joints as nearly as possible dust-tight—this applies equally to portable hand lamps.

"(2) This matter is covered by the requirements of previous regulations.

"(3) For the protection of cables and wires, the use of heavy gauge screwed metal conduits is recommended, care being taken that the conduits are electrically continuous and earthed.

"(4) As arcing or sparking of the contacts of switches, circuit breakers, or fuses cannot be prevented means should be adopted to render it harmless by enclosing them in dust-tight covers or placing them where there is no danger of firing the dust, the switch covers should be dust-tight, and the fuses should be of a type which will not cause an explosion."

Regulations in France.

As early as November 29, 1904, the Minister of Labor and Social Safety of France issued a decree pertaining to establishments where explosive dusts are produced. This was followed on December 17, 1912, by a circular containing further regulations and recommendations, but as most of these are not materially different from the regulations in the American and English codes, publication in full is not necessary. However, two of these recommendations are of particular interest.

"*D.*—It is recommended to water, or to sprinkle with heavy inert substances the places where the dust cannot be removed owing to exceptional circumstances.

"This recommendation aims at certain cases in which the cleaning recommended by the preceding paragraph cannot be carried out entirely owing, for instance, to repair work done in the shop.

"The neutralization of the dusts as recommended here will ordinarily be without any serious inconvenience; only in exceptional circumstances

should it be resorted to; moreover, one can always select the watering and sprinkling according to the nature of the dusty matter. * * * * *

"*H.*—It is recommended to paint white or blue, during the hot season, all the windows which are likely to be struck directly by the sunbeams.

"This measure has been objected to on the ground that it might decrease the brightness of the light and spoil the color or the tinge of certain products. Owing to the importance of this measure (glass elements likely to form lenses in the focus of which there may appear an ex-

This picture shows a large cereal mill and feed grinding plant at Peterborough, Ontario, being destroyed by fire that followed a dust explosion on December 11, 1916. Seventeen men were killed, 16 injured and approximately $2,000,000 worth of property destroyed. The explosion originated in the feed grinding department located to the left of the chimney shown in the center of the picture. The breaking of the sprinkler mains as a result of the explosion rendered the system useless in combatting the extensive fire that followed.

cessive elevation of the temperature), one must not discard the recommended measure except in the cases in which it is found to be practically impossible. It must be remarked that this measure is useful only during the hot season for the windows which are struck directly by the sunbeams, and that it does not fit at all in the establishments which have glass shed roofing only on the north side, a method of construction which tends to spread in many new plants."

An interesting method of designating the plants to which the regulations shall be applied is given. After specifying industries producing certain dusts a general rule is given to include plants producing "inflammable dusts which are capable of evolving, on burning in the air, a quantity of heat of at least 600 calories per cubic meter of mixture of air and dust." The amount of dust in the mixture is that which will just utilize

all the oxygen in a cubic meter of air. No statement is given of how this figure was obtained, but it is presumed that it represents the amount of heat necessary for the propagation of a flame through the most explosive mixture of any slightly inflammable dust and air.

CHAPTER V.

PHENOMENA OF EXPLOSIONS.

The term explosion[1] has been defined as follows: "If a system is in such a condition of physical or chemical equilibrium that a variation of that condition involving a transformation of energy and initiated at any one point will spread rapidly through the system of its own unaided action and without the supply of energy from without, then the system itself is said to undergo explosive change, and the change itself is called explosion. If the velocity of the change is small the explosion becomes a combustion, if large, a detonation." Judged from this definition, any degree of rapid combustion, from a small puff such as might be obtained by throwing a handful of dust over an open flame, up to the most violent detonation, may be considered as an explosion. In explosions in industrial plants it is possible to have either or both of these and any or all velocities and degrees of force between them, even in the same disaster. Usually there are two or more distinct reports. The first, that of the initial explosion, is often described as sharp and quick. It is followed by a second —a loud, rumbling sound more like thunder—which lasts for a much longer period. Sometimes there is a lapse of several seconds between the first and each succeeding report, but usually they are quite close together. The first report may be of varying intensity, depending upon the amount of dust in suspension and the degree of its confinement. The concussion and force of this explosion jars the dust from the ledges and projections and forms the cloud through which the secondary explosion propagates. The nature of the dust, the quantity in suspension or still remaining to be thrown into suspension as the explosion propagates, and the degree of confinement control the velocity and force of this as well as of each succeeding explosion.

But what is going on in the interval between the primary and secondary explosions? The force of the primary is gradually expending itself, the velocity of the flame is decreasing, and in some cases becoming almost negligible, while the dust settled about the plant and thrown into suspension is diffusing through the air, forming the cloud for the secondary explosion. The more intense the primary explosion and the greater the

[1] Watt's Dictionary of Chemistry, 1899, vol. 2, p. 530.

quantity of dust already in suspension as well as thrown into suspension, the shorter will be the time between the two explosions. The opposite is also true, for the less intense the primary explosion and the smaller the quantity of dust in suspension or thrown into suspension, the longer the time between the explosions. Conditions may be such that this time may be extended long enough for the flame of the primary explosion to die

A "choke-up" in an elevator leg caused this explosion and fire in a grain elevator at Peoria, Ill., on March 6, 1916. The damaged grain and destruction of the storage bins can be seen in the photograph.

out before a cloud of sufficient density is formed for the secondary explosion. But this can happen only when the plant is so clean that there is not enough dust to form an explosive mixture.

On the other hand, it is possible to conceive of a condition where the secondary explosion may occur even after the flame of the primary explosion has entirely died out. This might easily happen if the cloud is slow in forming and does not reach the flame of the explosion but later comes in contact with a small fire started by the explosion. In fact, the secondary explosion may occur at a point remote and in no way connected with the section of the plant first involved, or even in another building, if a spark or flame is present where a cloud of dust has been raised by the force of the primary explosion. It is not unlikely that the explosions in the mills adjoining the Washburn "A" mill at Minneapolis on May 2, 1878, occurred in this way. There may not have been a direct propagation of flame from one mill to the others, a short distance away,

but the force or concussion of the explosion in the Washburn mill threw dust into suspension in the other mills, and this was ignited by the open flames used for lighting purposes. A secondary explosion may be caused without the transmission of flame from one section to another if the cloud raised by the first explosion comes in contact with a source of ignition. As a matter of fact, the secondary explosion cannot occur unless the dust cloud comes in contact with a source of ignition. This may be the flame of the primary explosion or some other fire even at a very remote place. Consequently an explosion in one plant may follow an explosion in an adjoining one without the passage of flame.

A fact often overlooked is that the greatest damage is not always done in the vicinity where the explosion starts. It is often very remote. If the proper conditions for the propagation of an explosion are present the pressure increases as the flame advances, and the maximum pressure is reached at some distant point. However, it must be remembered that under normal conditions the maximum explosive effect is obtained where the dust cloud approaches or reaches the critical density. That this may be at some distance from the origin of the explosion has been demonstrated in many explosions. For instance in an elevator in Chicago the explosion started in the driers, but the greatest force was generated apparently in the tunnels under the storage tanks. An explosion in a feed mill in Illinois started in a grinding machine and propagated 375 feet through a blower system. It did no particular damage until it reached a dust collector and feed bin where the secondary explosion occurred, wrecking that part of the plant. An explosion in an elevator in Kansas City, in 1919, started in the basement. There was no direct communication between it and the upper portion of the elevator. Nevertheless, the explosion propagated up through the manlift and stairway at the side of the building and into the portion above the bins where the greatest damage was done.

In the relation of origin to damage, dust explosions differ from gas explosions for the gas mixture is usually localized,—not spread throughout the entire plant. Consequently the force of the explosion, greatest in the vicinity of the origin, gradually decreases and spends itself. The opposite is usually true in dust explosions. If these facts are not remembered during the attempt to locate the cause and origin of an explosion, erroneous conclusions may be reached.

Explosions in industrial plants vary greatly in intensity and in force. Some which are destructive are often heard but a short distance away. Such was the case at Weehawken, N. J., at Milwaukee, and in Buffalo. But at other times the concussion is so great that the explosion is heard and damage is done to property many miles away. For instance, it was reported that the explosion in the flour mill at Litchfield, Illinois, in 1893, was heard 25 miles away, and that there was not a house in the village of 8000 inhabitants but was more or less damaged. Buildings in nearby villages were also partially wrecked. People residing at a point 70 miles from Cedar Rapids, Iowa, heard the explosion which occurred there in 1919, and one woman who lived in a town 100 miles away claimed to

have heard it. The shock of the recent explosion in the elevator at Chicago was distinctly felt in Benton Harbor, Michigan, more than 50 miles away, and was also heard by persons at points 100 miles from Chicago.

That immense pressures are developed in some of these explosions is shown by the fact that heavy construction has often been ruptured, and heavy blocks of concrete have been carried considerable distances from the plants affected. A piece of concrete weighing more than 1,400 pounds

A large amount of grain was destroyed in this explosion in a grain elevator at Beach Grove, Ind., on June 14, 1918.

was found more than 300 feet from the Kansas City elevator following the explosion there in 1919. Reinforced concrete pillars 16 x 24 inches in cross section were blown down, and the 1½ inch steel reinforcement rods were completely stripped of concrete. These columns must have weighed fully six tons each and with their reinforcements should have withstood enormous pressures. Conveyor tunnels covered with 16-inch concrete were also blown apart, and heavy blocks were carried some distance. In the explosion at Port Colborne in 1919, heavy pieces of concrete cornices were blown several hundred feet from the plant, and heavy 8-inch steel I-beams were broken off, twisted, and thrown more than a hundred feet. Perhaps the most destructive force known to have been developed in an explosion of dust was generated in the North Western Elevator at Chicago. In one corner of the storage section, forty bins were moved on their foundation nearly half a foot. Cracks between these

and adjoining bins and their foundation piers indicate that they were lifted. The tanks and the grain they contained would probably weigh 300,000 tons. This gives some indication of the tremendous force of the explosion which occurred in the tunnels underneath these bins.

That such tremendous force has been developed in many of the more recent explosions is doubtlessly a result of the solid construction of the buildings. This affords little or no opportunity for the explosive force to vent itself. In the days of wooden elevators, no such force seems to have been developed in any explosions in these buildings. While the pressure and velocity of propagation of an explosion is largely dependent upon the inflammability of the dust and the percentage of it present in the mixture, it is also dependent upon the strength of the containing walls. It is doubtlessly true that with the critical or most explosive mixture of dust and air which may be present, very high pressures may be built up, but if the walls are of such strength that they will easily give way, this pressure will expend itself into the open air. It would seem, therefore, that the force of an explosion is influenced quite largely by the strength of the walls of the building in which it occurs. However, it is easy to conceive that if there is the most explosive mixture of dust and air present, sufficient pressure may be built up before the explosion reaches the weaker portions of the walls so that everything before it will be blown out regardless of the strength of the construction. With less explosive mixtures there is no doubt but that the force of the explosion will propagate along the lines of least resistance. This was shown in an explosion on the top floor of a cereal mill in Buffalo which propagated through a large double door into a large room adjoining and apparently extended throughout the entire upper floor without doing any damage to the walls or any portion of the plant except to raise the roof which, when it dropped back, was a few inches out of place. No fire followed this explosion. The explosive mixture present in this portion of the plant apparently developed only sufficient pressure to raise the roof. This instance would favor the suggestion made at one time that all roofs be of light construction, in fact, that some of them be hinged so that in case of an explosion they might open and allow the pressure to vent itself. The only trouble with this plan is that explosions do not always happen on the top floor of a plant. They start in all sections of the building and vent themselves wherever possible. In an explosion in a plant in Buffalo the side walls were blown out while the roof was left intact.

It has been suggested that the force of a dust explosion is usually in a lateral direction. However, considering the above illustrations and many others which could be given, it would seem that the force is exerted in all directions at once, and that it only seems to go in one particular direction because the retaining walls on that side are weaker and give way more readily. That the force is lateral is shown by the damage to surrounding property, but that it is also perpendicular is shown by the fact that flames and debris are often thrown a considerable distance into the air. It is stated that in an explosion at Richford, Vermont, in 1908, flames shot more than 200 feet into the air, while pieces of the corru-

This explosion took place on May 20, 1919, in the elevator of a feed grinding plant at Milwaukee, Wis. Three workmen were killed, 4 injured and property amounting to $150,000 was destroyed. The explosion originated in the central elevator leg on the first floor and propagated to the bin floor causing extensive damage to the top of the elevator, which can be readily observed in the picture.

gated iron roofing were carried to points two miles distant from the plant. In the explosion in the Farmers' Elevator at Fife, Montana, in December, 1918, the entire machinery and the head of one of the elevators were blown out through the roof of the plant, and in the more disastrous explosion in Cedar Rapids, Iowa, in 1919, one man estimated that flames shot fully 500 feet into the air. Debris was picked up more than 2½ miles from this plant.

While a minor explosion or even one of greater intensity in a large container will expend its force through the weakest part of the construction, vents are not always fully effective in relieving the force of an explosion. This fact was demonstrated in the explosion in an aluminum plant at Manitowoc, Wisconsin. The portion of the plant in which the explosion took place was of daylight construction. Normally, it would be thought that the large number of windows would have allowed the force of the explosion to be vented instantly. No doubt they did have considerable effect. Nevertheless, the walls were bulged out badly. In a similar explosion at Buffalo which started near the boot of an elevator, the steel casing was blown apart, even though the elevator head was off, giving clear passage to the outer air through the top of the elevator. In a minor explosion in a machine grinding gum in the plant of the American Graphophone Company at Bridgeport, Connecticut, in 1918, the machine was badly damaged even though it was vented. It was thought that the vent modified the effects of the explosion, but it did not relieve all of the pressure.

It may seem an anomaly to say that part of the destruction of an explosion in a mill may be the result of suction rather than of pressure, since it would be expected that pressure alone would be developed. However, after the passage of an explosion the very high temperature which was developed begins to fall rapidly and a high vacuum is often formed. There is an inrush of air to fill this space and a strong suction is created. In referring to this phase of explosions in mines, the Bureau of Mines[1] states: "Following the passage of the pressure waves there is a depression below atmospheric pressure, which is caused by the cooling of the gaseous products of the explosion and by the ejectment of the gases by the violence of the explosion. The depression causes a violent movement or inrush of air from other parts of the mine, or from the outside, to fill the partial vacuum." In mine explosions at least it is also possible to have another effect after an explosion, where even greater pressures may be obtained than those created in the passage of the explosion. This is indicated by the following statement of the Bureau of Mines[1]: "The records of the European experiments have shown us that as the main pressure wave travels ahead it throws off reflex pressure waves that travel back toward the origin, and that if the origin is at the closed end of the gallery, the pressure may be raised above what it was at the time of ignition."

A peculiar condition was noticed in the investigation of the explosion in the government elevator at Port Colborne, Canada. That pressure was developed in the basement of the elevator, was evident from the fact that one of the employees who was standing near a door, on the side of the basement opposite the boot of the elevator in which the explosion started, was blown out of this door against a pillar a few feet away. However, the property damage in this part of the building indicated that a strong

[1] U. S. Bureau Mines Bull. 56, p. 11.

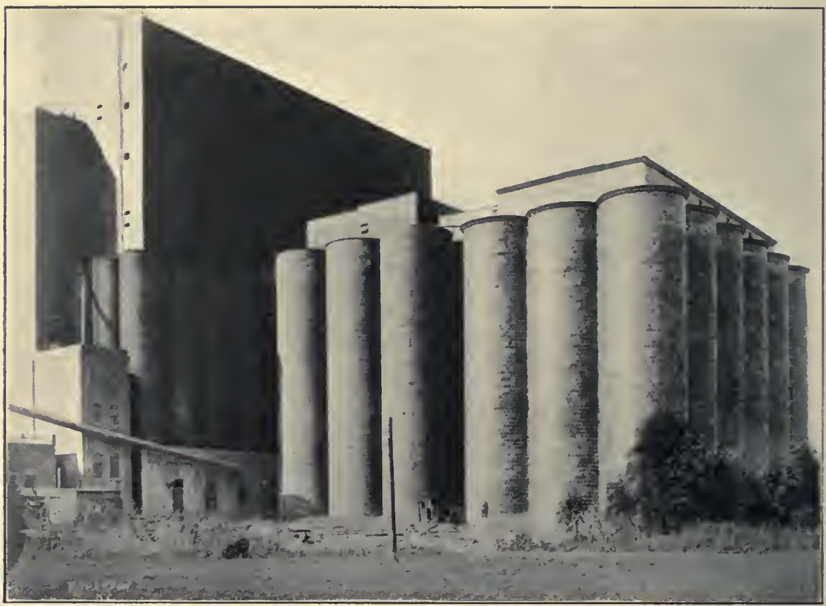
This spectacular fire followed a dust explosion in a large terminal grain elevator in Brooklyn, N. Y., October 13, 1917. The explosion occurred during the period of the World War when every effort was being exerted to conserve our food supply. The grain loss as a result of this explosion was estimated to be the equivalent of bread rations for 200,000 men for an entire year. This explosion initiated the special educational and prevention campaign by the U. S. Department of Agriculture and the U. S. Grain Corporation, for the purpose of preventing losses to life, property and foodstuffs.

vacuum rather than much pressure was developed. The basement was well lighted by windows on three sides. Most of the glass of these windows was out of the sashes, but instead of being found outside which would indicate pressure, it was found in small pieces all over the floor of the basement, showing that it was drawn in by suction. That this suction was considerable was indicated by the fact that some of this glass was found 30 to 40 feet from the walls. It is quite probable that it might have been blown out by the first small pressure in the basement if it had been in large panes and had not been well set. It withstood the slight pressure but was unable to withstand the suction. It is not unusual in dust-collecting systems and conveyor pipes for a pipe to collapse following the passage of the explosion instead of being blown apart by the pressure developed within. Such was the case in the explosion in a starch factory in Oswego, New York, September 30, 1907. That many walls have been drawn in instead of blown out indicates that a great deal of other damage to property is the result of suction rather than pressure.

Dust collecting systems are usually installed with the idea of being a protection as well as a means of cleanliness. However, they are known to have initiated and spread explosions. An explosion in a flour mill in Denver in January, 1918, is supposed to have started in the dust collecting system, possibly because of sparks struck by the blades of the fan against the sides of the casing. However, there was also evidence that this explosion started in the rolls, and that it was drawn into the dust collecting system, through which it propagated out into the plant. Two similar explosions are known to have occurred in flour mills, one at Benton, Pa., which started in the rolls and propagated through the dust collecting system, and the other at New Prague, Minn. In 1914-15, explosions in a starch and dextrine plant at Edgewater, N. J., were drawn into the dust collecting system. They propagated through it to the dust house and from there to other portions of the mill causing considerable damage. The explosion in the aluminum plant at Manitowoc started in the dust collecting system as a result of a piece of heavy wire getting into a fan where it struck sparks which ignited the aluminum dust. The explosion propagated back through the pipe and out into the room from which the dust was being drawn.

It is difficult to state just what was the cause of a number of explosions which have occurred in dust collectors. In some of these cases it might be that a flame or some smoldering material was drawn into the collector or foreign material may have been pulled into the suction pipe, creating sparks. It is possible that static electricity was developed within the collecting system. Such explosions occurred, for instance, in a cereal plant in Cedar Rapids, Iowa, on the 11th of January, 1902; in a cereal plant at Canal Fulton, Ohio, on the 21st of December, 1907; in flour mills at Nashville, Tenn., on the 30th of July, 1908; and in another mill at McPherson, Kansas, on the 8th of March, 1911. Details regarding the installations in which these explosions occurred have not been obtained, but indications are that dust was being collected from grinding machines or other equipment in which a quantity of dust was created. In

a starch plant in Oswego, N. Y., on the 28th of September, 1907, an explosion occurred in the cyclone feed to the starch grinding room and extended to the dust collectors nearby, causing an explosion which tore off the walls of the building and wrecked the cyclone and conveyor pipes. A similar explosion occurred in July of the same year, but it was not quite so extensive. While dust collectors have their advantages and tend to



Large terminal grain elevator in Kansas City, Mo., before explosion on September 13, 1919.

prevent explosions, care must be taken to see that they are operating effectively, that dust is not allowed to accumulate in the suction pipes, and that they are so installed that should an explosion start and be drawn into the system, there would be no possibility of its propagating into other sections of the plant.

It is a peculiar phenomenon that in many cases where explosions have occurred in industrial plants, they have not been heard by men working in the plant. The severe explosion which occurred in Cedar Rapids, Iowa, in 1919 and which was reported to have been heard 100 miles away, was not heard by a man in the boiler plant. At Port Colborne a man in the basement of the plant did not hear the explosion, although he was thrown down by the force of it. Four men who were working in the flour mill at Benton, Pa., at the time of an explosion, some of whom were burned by the flames, did not hear a single sound except the rush of air as the flames approached them, while people outside the mill who witnessed the

explosion heard three distinct reports. This was also the case in an explosion at Cheney, Wash. The three men in the mill heard no report, while people outside and near the mill heard three distinct reports. Two of these came from the mill proper and one from the warehouse. It would appear that there was some lapse of time between the explosions in the mill and the one in the warehouse, since the latter did not occur until after an alarm of fire had been turned in, and the owner of the plant had had time to come from a short distance. Just what the cause of the explosion in the warehouse could have been has not been determined, but the dust was probably stirred up by the original explosion and ignited when the flames of the fire reached it.

Many explosions occur at the most unexpected times and originate in most unexpected places. It would hardly be expected that an explosion would occur in a plant after it had closed down, but such has been the case in several instances. An explosion in an elevator in Minneapolis occurred in the early evening after the plant had been shut down for several hours. In fact, there was a series of explosions in this plant. The odor of fire had been noticed by the watchman, but he had been unable to locate any smoldering or burning material. Shortly after he had made a round in the upper portion of the elevator, an explosion occurred there, apparently of a minor nature. This was followed by a series of explosions as the flame propagated through the plant. Two of the most destructive explosions which have occurred in elevators recently, started while the elevators were not in operation. One of these, at Port Colborne, Canada, started a little over an hour after the plant had been shut down for the lunch period and just as it was about to be started. However, the cause of the explosion was an unnoticed smoldering fire started just before the plant was closed down. The other, an explosion in the North Western Elevator in Chicago in March, 1921, occurred late Saturday afternoon, several hours after the plant had been shut down. However, dust was being stirred up in the cleaning of the grain driers. A similar explosion occurred in Kansas City, in September, 1919, on a Saturday afternoon when the plant was closed down and was being cleaned. A peculiar minor explosion occurred in a cereal mill in Buffalo, in 1920, when the mill was not in operation and repairs were being made. It would hardly be expected that a dust cloud would be raised in the repairing of a steel elevator leg, but such was the case in this mill, and the dust was ignited by a piece of hot metal cut from the boot of the elevator.

Several instances have been given of explosions caused by sparks from foreign material passing through grinding machines and by static electricity in various portions of plants. However, sparks may be struck in other ways and may cause destructive explosions, as they did for instance, in a shoddy mill in Cleveland, on February 27, 1910, when an employee was cleaning out a vault into which dust was discharged from a cyclone collector. It is presumed that a spark was struck by a hoe which the employee was using. An explosion in the dust collecting system of a wood working plant in Boston in 1918 was started by sparks from an emery wheel several feet from the suction pipe into which they were

drawn. The explosions in elevators at Weehawken, N. J., in 1915, and at Baltimore, in 1921, were supposed to have been caused by sparks struck by foreign material in the grain as it fell against the sides or bottom of a very deep bin. In both cases only a few hundred bushels of grain had been run into the bin at the time of the explosion.

The two explosions which occurred in the starch and dextrine plant at Edgewater, N. J., in 1914-15, as a result of the accumulation of dust within the reels, were caused by static electricity. Another unusual ex-

View of same elevator after explosion which originated in basement of elevator, during a clean up period, and traveled up through the elevator shaft on the left. Fourteen workmen were killed and 10 injured.

plosion occurred in a rubber factory in Boston, on February 6, 1913. Two men were pouring barrels of flowers of sulphur into a sieve enclosed in a wooden boxing. There was a sudden flash from this box, followed by a slight explosion in which the men were badly burned. A similar explosion occurred in a rubber works at Hartford, Conn., on February 23, 1914. In fact, there were three explosions in a sulphur conveyor and sifter on the top floor of this mill during a period of two weeks. The last of these explosions, however, was the most violent and much of the machinery was blown apart. The only cause which could be assigned to these explosions was static electricity generated by the agitation of the very fine sulphur over the screen.

Friction developed in any portion of the mill, to such an extent that coals or flame result, may start explosions at different places. An explosion of cork dust in a mill in Philadelphia on February 1, 1919, resulted

from a broken belt which wound up on a shaft and developed sufficient friction to start a fire which ignited the dust. Friction in elevator heads is not uncommon. The explosion at Port Colborne originated in this way although at first it was thought that it was caused by the ignition of dust by a belt in the basement which, by riding on one side of the pulley and rubbing against the wall, had created sufficient friction to cause the rubber of the belt to smolder. An explosion in a brewery in New York was supposed to have been caused by foreign material striking sparks as it was conveyed through the screw conveyor along with the malt. An unprecedented incident led to a very disastrous explosion in a mill in England, in 1911. Apparently a large drive belt had become so weakened that it broke. As it fell the large cloud of accumulated dust which it stirred up was ignited by the flames from a fuse which blew out at the same time.

There has been some discussion as to the actual value of sprinkler systems in preventing destruction by dust explosions. Investigations show that they are very effective in extinguishing fires following explosions, provided the sprinkler pipes or header pipes have not been broken by the initial force and the system thereby rendered useless. A number of such instances are on record. However, an explosion occurred in a starch factory in Brooklyn, N. Y., on March 12, 1901, which did not put the sprinkler system out of commission, but the fire which followed was of such intensity that although 40 sprinkler heads were opened they were unable to control it. It is barely possible that if a sprinkler head could be opened in front of an explosion so that the propagating flame would have to pass through the sheet of water, explosions might be prevented from extending to all sections of a plant. However, the sprinkler heads are usually not opened until the flame has passed, and consequently they have little effect in preventing or stopping an explosion except, perhaps in extinguishing a small fire which might be the cause of an explosion. If not damaged, sprinkler systems are effective in putting out the fires which occur after an explosion, but when the force is as great as it was in the explosion in Cedar Rapids, in 1919, where it broke water mains several feet underground and put the entire sprinkler equipment out of commission, it can readily be seen that they cannot be effective in extinguishing fires. In several other cases sprinkler systems have been made ineffective as the result of explosions.

Some explosions have been so destructive and have left so little of the plants intact that it has not been possible to determine their causes or to note their phenomena. In these cases very peculiar effects upon the surrounding property have often been observed. Perhaps some of the most interesting resulted from the explosion in the starch factory at Cedar Rapids, Iowa. There was hardly a building within three-quarters of a mile or more of the plant which did not feel direct effects of the explosion, and in many cases all of the window glass was broken. However, the superintendent's office, a small one-story structure about 20 feet square, located on the grounds of the mill and but a short distance from it, was not damaged in any way. The highest building in the town suffered no

A near view of the terminal elevator in Kansas City, Mo., damaged by a dust explosion, showing the point of origin in the basement and the damage to the reinforced steel and concrete construction.

loss whatever from broken windows. This may have been a result of the fact that these windows were somewhat smaller in size than the others, but it would also appear that there was not the same explosive effect in this locality that was shown in other places. One peculiar thing noted in the case of double windows was that often one of them was blown inward while the other was forced outward, and, in the case of some large single plate-glass windows, the upper portion was blown inward while the lower half was blown outward, or vice versa. On either side of broken windows there would be unbroken ones.

The windows on one side of a building might be blown out while those on the other side would be blown into the building. Along streets running at right angles to those leading toward the mill, the windows on the far sides were drawn in, while those on the side toward the mill were blown out into the street. Sometimes those on the near side were blown in while those on the far side were blown out into the street. This was apparently due to suction or else to a back-pressure wave. The windows of a small frame church in the vicinity of the plant were intact, but the wall toward the plant was badly cracked and bulged outwardly in the direction of the mill or toward the explosion. All the windows and doors of the church were closed, and it is hard to conceive how this damage could have been done except by suction created by the passage of the explosion wave. One of the most pathetic cases which has been noted in connection with this or any other explosion was that of a baby a few months old being blown out of bed by the force of the explosion, dying shortly thereafter as a result of injuries.

CHAPTER VI.

DUST COLLECTION AND REMOVAL.

The dissemination of dust must be controlled before dust explosions can be prevented. Attention and study have been given to the subject of dust collecting and the efficiency of dust collectors in various industries because of the fact that a number of disastrous dust explosions have occurred in plants considered modern so far as dust collecting was concerned. The fact that in a number of cases the explosion has propagated through the dust collecting system, shows the necessity for a thorough investigation to determine the efficiency of some systems.

Little attention was given to the subject of dust collecting in the milling industry previous to the advent of the middlings purifier. The use of this machine made it necessary to provide some means of taking care of the dust blown from the purifier fan. Accordingly rooms were partitioned off or built in some unoccupied space in the mill and the dust blown into these settling chambers through trunk lines. These rooms were tightly closed with the exception of one or two small openings which were fitted with baffle boards or covered with cloth which permitted the air blown in by the fan to escape while the dust settled to the floor. At intervals workmen removed the dust which had settled and accumulated on the floors of these rooms.

The stive or dust rooms used prior to 1880 wherever it was necessary to collect dust were large and allowed a great quantity of dust to remain in suspension during operation. Many explosions occurred in this primitive dust collecting equipment. The explosion in Minneapolis in 1878, and at Litchfield, Illinois, in 1893, proved very conclusively the danger of this method of collecting. Both of these explosions occurred in flour mills where stive rooms were used to collect the dust. They directed attention to the necessity of developing some more satisfactory and safer dust collecting system. Larger mills were being built and the removal of dust was becoming quite a problem. It is probable that this problem as well as the explosion hazard hastened the development of our improved types of dust collectors. The development of the modern dust collecting systems passed through many interesting stages. One of the first collectors consisted of a large box with hoppered sides and a conveyor at the bottom to remove the dust settlings. A series of curtains or baffles within the

box deflected the air currents and caused the dust to drop. Another form of collector had a vertical cylindrical chamber with cloth walls arranged in zig-zag fashion to give the maximum of filtering surface. It had a conical hopper which discharged the dust through a weighted valve into a spout or conveyor. A later step in the development was the introduction of the dust-laden air at the side of the cylinder instead of at the

Canadian Government Elevator at Port Colborne, Ontario, prior to explosion on August 9, 1919.

top which led to the discovery that the conical hopper gave a whirling motion to the air which deposited the dust at the bottom of the hopper. This machine was the forerunner of the modern cyclone collector.

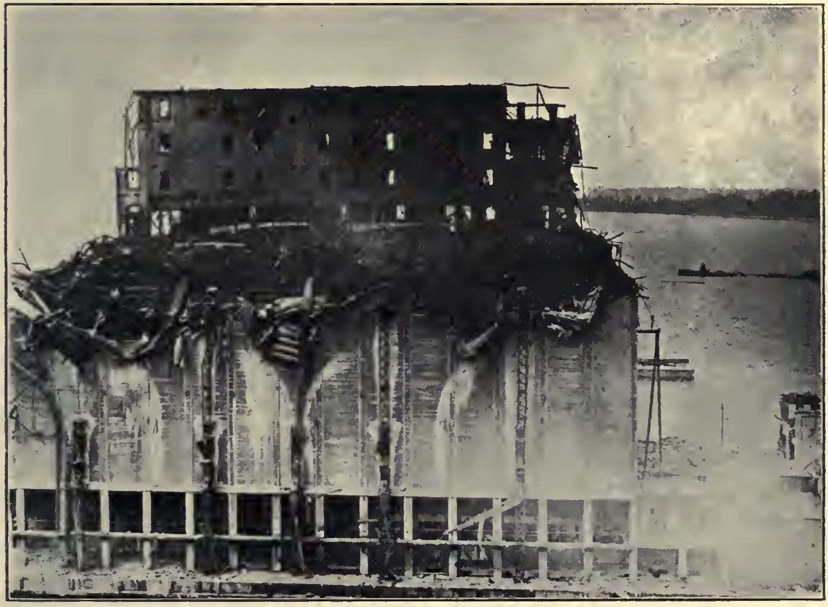
Many improvements have been made in the cyclone type of collector in recent years. Experiments have shown that the best results can be obtained with certain length cones, and tests have shown the proportion which should exist between the inlet, outlet, and discharge for the most efficient operation of the collector. Some difference of opinion naturally exists on these questions but it is noticed that the manufacturers are gradually working towards a standard type of apparatus for each distinct purpose. A recent invention makes it possible to use the cyclone type

of apparatus as a dust separator as well as a collector. Adjustable fins attached tangentially to a pipe centrally located within the collector make it possible to separate dust of various degrees of fineness from the entire amount of dust drawn to it by the suction fan. The early models of the present cloth collectors were quite different in appearance from the ones now in use although the principle on which they operated was practically the same. Cloth-covered wedge-shaped frames were placed symmetrically around a hollow horizontal cylinder and arranged so that the entire apparatus revolved on the axis of the cylinder. Within the cylinder was placed a stationary screw conveyor. The dust-laden air was blown into the cylinder and entered the cloth-covered sections through which the air filtered while the dust was retained. As each compartment was carried over the conveyor by the revolving of the collector the dust was deposited through the bottom of the wedge-shaped section into the conveyor which carried it to a spout or secondary conveyor. The stockings used at the present time on this type of machine were substituted for the wedge-shaped frames simply because more filtering surface could be obtained in this way. An apparatus somewhat different from the cloth collector just described is known as the tubular collector. This type consists of a number of long cloth tubes tightly stretched between an upper and lower chamber. Both the upper and lower ends of the tubes may be opened or closed mechanically and this mechanism is usually arranged to operate automatically. In operation the dust laden air enters the upper chamber and passes into the tubes which at the time are closed at the bottom. The air passes through the cloth tubes while the dust is retained. At given intervals the tops of the tubes are closed, the bottoms opened, and the dust automatically shaken into the lower chamber. The bottoms of the tubes are then closed, the tops opened and the process repeated. These collectors are generally arranged in series so that the dust can enter one section of tubes while the other section is being shaken.

A machine quite similar in construction to the tubular collector is known as the suction filter type of collector and consists of a number of cloth stockings or tubes within a cylindrical shell. The tops of these stockings are always closed while the bottoms remain open. The dust laden air is drawn in at the base, which is usually in the form of a cone, and after dropping the heavier dust particles passes up into the stockings where the fine dust is caught while the air passes through and out at the top of the collector to the suction fan. At intervals the flow of the air is changed by automatically operating valves and the reverse air currents loosen the fine dust deposited on the stockings and an automatic knocker shakes it into the cone beneath. From here it passes through a revolving damper or air lock to conveyor, spout, or storage bin. Like the tubular collector, these machines are usually arranged in series to permit the dust laden air to enter one compartment while the stockings in another are being cleaned.

In addition to the systems of dust collecting referred to above, another type, operating on an entirely different principle, has been placed on the market and within the last few years has been adapted to several different

industries. This system is known as the Cottrell process or the electrical precipitation method of dust recovery. At the present time it is used principally in the recovery of valuable metallic dust carried away as fume from metallurgical furnaces and for such work the equipment has been standardized and thoroughly tested in commercial operation. It also finds application in the precipitation of obnoxious gases which would otherwise be disseminated over the surrounding country by some of our industrial



View of elevator at Port Colborne, Ontario, after explosion in which 10 men were killed and 15 injured, and property and grain damaged to the extent of $750,000.

plants. With certain variations it may possibly be adapted to the precipitation of organic dusts and thus prove of value in plants where the collection of the fine dust is now a problem. However, its use in the precipitation of inflammable dusts as yet is not fully developed.

Most milling plants throughout the country have taken advantage of the improved systems and have adopted either cyclone or cloth filter collectors. However, in a few cases the old system has been retained and an explosion is reported to have occurred as late as the spring of 1905 in a flour mill at Liverpool, England, where a stive room was in use. The investigation indicated that the explosion, which was followed by a disastrous fire, originated in this dust chamber.

In August, 1920, an explosion occurred in an industrial plant where hard rubber was being ground. The explosion, which started in the basement of the building where the grinding was being done, quickly spread

through the dust pipe lines to the dust room. In this installation, a number of cloth covered frames were arranged in rows within a dust room and the fine rubber dust recovered by blowing the dust laden air through this filter. Fortunately the dust room in this case was located on the roof of the building and the violent explosion, which occurred when the flames reached the large quantity of dust in suspension at this point in the system, completely destroyed the dust room without seriously damaging other sections of the plant. An inspection tour of the country conducted in the interest of fire prevention disclosed the fact that in some cases this order was reversed and the dust room located in the basement of the building.

It has been demonstrated that the modern dust collecting systems are an improvement over the old dust room, and in view of the fact that by their use the fire hazard is reduced, the handling of dust made easier, and working conditions are made healthier for the employee, it is difficult to understand why the use of dust rooms is continued in any plant.

The efficiency of the two dust collecting systems, the cyclone and the filtration, varies in the different industries. Some dusts of a fibrous nature stick to the stockings of the cloth collectors and are not discharged readily. This soon reduces the filtering area and impairs the efficiency of the system. Other dusts are sometimes too light to be readily deposited in a cyclone collector. With these the cloth collector will work more efficiently but from a fire hazard viewpoint the metal cyclone collector has the advantage over the cloth collector. In cold climates, however, the cloth collector is often preferred to the cyclone because the latter generally exhausts outside and it becomes difficult to warm the building during cold weather. The need for dust collecting in our modern industries has grown so great because of the necessity of saving by-products and the necessity of preventing the dissemination of dust on adjacent property, that the designing and installation of dust collecting systems has become a specialized field and there are a number of engineers who give their entire time to the subject. The type of collector best suited for any particular purpose can be determined only by experiment or by making a thorough study of the problem as related to some similar installation successfully operating, consequently where the installation of dust collecting equipment is being contemplated in a new industry the matter should be taken up with one who is thoroughly familiar with such work.

Although the present systems are decided improvements over the old in many ways, it is apparent that the perfect dust collecting system has not yet been devised. The fact that explosions and fires have propagated through the present systems indicates that there is still room for improvement. With the present method, dust is collected from a number of sources and drawn by air currents through small pipe lines into larger ones, where it is in turn carried to the depositing point in the system. Often one main trunk line will serve an entire plant and draw dust through its branches from all parts of the building. Should a fire occur at any point where the suction is applied, it is drawn into the system and if enough dust is present in the pipe line, the flames may be carried to

the depositing point or they may flash back through the system to all parts of the plant. During the investigation of an explosion in a feed mill it was discovered that the flames had propagated for a distance of 370 feet through a steel trunking used for conveying the ground feed from the mill to the storage bins located in another building. It can readily be seen how easily and quickly a fire could spread throughout

Looking down from work house on storage bins at Port Colborne, Ontario, Elevator after the explosion. This type of bin construction permitted the accumulation of large quantities of dust.

the entire plant in this way. The size of dust collecting apparatus has been increased to keep pace with our enlarged industrial plants until now in many cases dangerous quantities of explosive dust are contained within the system and the apparatus, designed to be a remedy, has become a hazard.

Static sparks will ignite certain dusts and dusts blown through a pipe will under certain conditions produce a static charge. Metallic sparks will also ignite certain dusts, and such sparks can be produced in our present dust collecting systems. Cases on record show that sparks were produced in the fan when one of the blades became loose and struck the fan casing. In other cases foreign material, such as flint, wire or other metallic substance, has entered the fan and when struck by the blades produced sparks which ignited the dust mixture.

Many improvements designed to overcome this difficulty have been made in our present systems. Equipment has been designed which makes possible the placing of the dust collector between the fan and the source of dust. The air is drawn through the collector by the fan where the dust is separated and only clean air passes through the fan. This practically eliminates the possibility of dust ignition within the fan. By properly grounding the entire dust collecting system, the accumulation of static can be prevented, and the danger of dust ignition by static sparks eliminated.

It has been shown above how two of the hazards of our dust collecting systems have been overcome. The principal feature which remains to be remedied is the presence within the systems of dust in dangerous quantities where it can act as a medium through which a fire or explosion in one section of a building will spread to all parts of the plant. Attempts have been made to solve this problem by placing the collector outside the building, and in some cases even the main trunk line has been placed outside. Some manufacturers, in addition to placing a large part of the equipment outside the building, have reduced the size of each unit or, in other words, they have installed more units of smaller size in order to reduce the number of points served by each collector. Evidently this is the method which must be followed in solving this phase of the problem, and some specialists in this line of work go so far as to claim that each machine or piece of equipment producing dust should have a separate and distinct dust collecting system.

Dust removal is as important as dust collecting. Of course, the proper method is to collect the dust at the point where it is produced but even with the most improved systems some of it escapes and settles on floors, beams, and ledges about the plant. Under some conditions, as in the conveying of material about a warehouse, dust may be produced which it would be very difficult to collect. For such cases some system of dust removal should be installed and attention given to the prevention of accumulations at points where the dust could be thrown into suspension to furnish the means by which a primary ignition could grow into a disastrous dust explosion. The push-broom method of dust removal is the one in general use throughout the country. The dust is brushed from machinery, ledges and the various lodging places about the building to the floor by small hand brushes. It is swept into piles by means of brooms or long-handled floor brushes and then shoveled into bags or receptacles and removed. In the larger plants, spouts with openings on the various floors are provided and the dust swept up from the floor is fed into the spout which carries it to a screen where the good material is separated from the refuse and sent to the feed mill. In other cases, the dust is swept into a suction pipe which carries it to a dust house located at a distance from the main plant.

In a few plants suction floor sweeps have been provided consisting simply of a suction pipe with a flare at the floor level. When the valve is opened the inrushing air carries with it the dust which has settled on the floor within a radius of 10 or 15 feet from the spout. As in the systems

previously described, hand brushing must be relied upon to bring the dust to the collecting point.

Compressed air is used in certain cases, especially for blowing the dust from motors and machines where it could not be reached with brushes. A long pipe with an elbow and nozzle at one end or a compressed air hose line attached to a long pole is sometimes used to remove the dust from beams and ledges high overhead. This method not only makes

Result of an explosion of cocoa dust in a chocolate plant at Burlington, Vt., on April 25, 1918, in which 3 lives were lost and $500,000 damage done.

necessary a second handling of the dust after it settles on the machines and floor below but is also a dangerous practice since it produces large dust clouds which may ignite if an electric lamp should be accidentally broken during the cleaning process or a spark or other source of ignition should happen to be present at the time the dust is in suspension.

The vacuum cleaning system as used in many of our homes has been adapted to several industries and is reported to be giving satisfactory service. Nozzles attached to flexible hose lines are provided at intervals throughout the plant and it is an easy matter for the operator of a dust producing machine to clean the floor and ledges and even the machine itself. Some attention has also been given to the developing of a vacuum suction system for mills and elevators. One of the companies actively interested in dust explosion prevention work installed an experimental vacuum suction cleaner in its plant. Although this equipment was quite small it was sufficiently large to give some very interesting results when operated in comparison with workmen using the push-broom method of cleaning. The exhaust fan for this equipment was designed to handle not less than 800 cubic feet of air per minute, and it was found advisable to have at least 100 cubic feet of air per minute entering the suction tool

in order to insure rapid and thorough cleaning. The experiments indicated that from five to fifteen horse power was necessary to operate such a system, depending upon the number of suction tools used at one time. Riser pipes 2½ inches in diameter were installed with an opening on each floor and enough risers were provided to permit the reaching of any point on each floor with a 50-foot vacuum hose.

During tests conducted at the plant the vacuum cleaning system operated quite satisfactorily. The dust on the floor was removed quite easily and the beams and ledges were thoroughly cleaned. As a contrast to the vacuum system two men were put to work sweeping on the same floor but at the opposite side from where the vacuum system was in operation. The sweepers stirred up quite a dust cloud while they were working but the air on the side of the room where the vacuum system was in use remained very clear. When the men had completed the sweeping the vacuum system was used in going over the section they had just cleaned and a considerable additional amount of dust was removed by this method.

Very satisfactory results were obtained with the vacuum system in cleaning floors, walls, and ledges. It was quite difficult, however, to remove the dust from irregular surfaces as found on many of the machines with the suction nozzles in use at the time. Possibly different nozzles could be obtained which would do this work satisfactorily. The demonstration gave very encouraging results and it is felt that with a few changes the vacuum system can be made to give satisfactory service in mills and elevators for cleaning and dust removal.

CHAPTER VII.

STATIC ELECTRICITY.

Static electricity has already been referred to as a possible cause of explosions and fires. In fact it has been established that the discharge of static electricity has caused fires and explosions. In the preceding chapters, however, there has been no detailed discussion of this phenomenon, to which, until recent years, no credence has been given. A discharge of static electricity may jump to a person's hand or some other part of the body and only a tingling sensation is felt. This may continue for some time and no great discomfort other than this prickling sensation is experienced. That is, there is no burning sensation, and no evidence of heat sufficient to burn. The spark made by the discharge of static electricity has, for this reason and others, been considered too cold to ignite anything. Some discharges of static electricity may not ignite anything, but other discharges of it will and do ignite many things. It is the latter which it is proposed to consider in this chapter.

Static electricity is exactly what the name "static" signifies, that is, electricity at rest. It is often known as frictional electricity as it is generated by the rubbing of two dissimilar bodies against each other. One takes a positive charge and the other a negative charge. The charges will remain upon the bodies and be gradually dissipated into the atmosphere unless they come in contact with or near a less charged, uncharged or oppositely charged body, when they will pass from the one body to the other to be neutralized. This will occur when the bodies come near enough to each other so that the charge can break down the resistance of the atmosphere and jump through it. In so doing a spark, which is known as the discharge of static electricity, is formed. It is this discharge spark which may cause the ignition of inflammable materials with a resulting fire or explosion.

One of the places in industrial plants where the presence of static electricity is noticed frequently is about moving pulleys and belts. Here it is generated by the friction of the belts on the pulleys, and its presence is usually revealed by a passage of sparks between the pulley and belt on the side where the belt leaves the pulley. Often distinct sparks are not noticed, but instead there is a blue haze which seems to hang between the pulley and belt. This is known as the "corona" effect. It is usually considered that the static electricity which is generated by moving pulleys and belts is entirely due to friction. As will be brought out later this may be

A sugar refining plant in Brooklyn, N. Y., destroyed by an explosion and fire on June 13, 1917. Twelve men were killed, 24 injured and the property loss estimated at $1,000,000.

largely true, but since the movement of bodies through air causes them to become charged with static electricity it seems reasonable to say that at least some of the static on the pulleys and belts is developed by their movement through the air, being caused by the friction between them and the air. Static electricity is generated on all machines in an industrial plant, but more especially on those which are rapidly moving, such as grinding machines, elevators, conveyors and screens. It is also generated

by the movement of the dry manufactured product, flour or feed, for instance, as it passes through the process. The friction between this material and the different parts of the grinding or pulverizing machines may cause the generation of static electricity, as may also its movement through elevators, spouts and other conveying equipment.

The static electricity generated in the various parts of an industrial plant may accumulate in some cases, while in others it may be dissipated into the atmosphere or be carried off from the machine as fast as it is generated. This depends largely upon two important factors, one, the amount of moisture present in the surrounding atmosphere and known as the humidity of the air, and the other, the construction, arrangement and installation of the machinery. Moist air is a very good conductor of static electricity while dry air is a poor one. Consequently, when the relative humidity is high, the static electricity which is generated is easily conducted away by the atmosphere or, as more commonly understood, it is dispensed into the atmosphere. Under these conditions the static electricity may go off so rapidly that it is not observed to be present on the machines. Also, an unbroken electrical connection between the ground and the point at which the static electricity is generated will prevent the accumulation of static electricity because it will be conducted away as fast as it is generated. When, however, there is no electrical connection to the ground and the relative humidity is low, the static electricity will accumulate and its potential continue to increase until it becomes great enough to break down the resistance of the air between the body on which it is accumulating and a body nearby, at which time a spark of discharge will jump from the charged to the uncharged body. If the static electricity is being generated in sufficient quantities there will be a continuous breaking down of the resistance of the air with a continuous passage of static electrical discharge sparks.

It has been stated above that static electricity is generated by the friction of two dissimilar bodies. Such friction is commonly thought of as occurring between two comparatively solid and large bodies, as pulleys and belts, or the common laboratory illustration of rubbing a glass rod or a piece of hard rubber with woolen cloth, but it is not necessary to have large and solid materials, nor to have them moving very rapidly. Dr. W. A. D. Rudge[1] has shown very conclusively that even the raising of a small cloud of dust, or the movement of such a cloud in the air will create static electricity. He has demonstrated the fact that charges of static electricity are formed in the air, or imparted to it by dust clouds raised by winds blowing over the surface of the earth or by the movement of large bodies, as animals or automobiles over dusty roads. This was shown to be true not only with the ordinary dusts of fields, roads, etc., but also with all sorts of finely divided substances. When a small quantity of dust, such as flour, was placed upon the plate of an electroscope and suddenly blown away, the electroscope became charged, the magnitude of the charge depending to some extent upon the fineness of the dust.

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[1] "On the Electrification Associated with Dust-Clouds." W. A. D. Rudge, Professor of Physics, University College, Bloemfontein, S. Africa.

By raising a cloud of dust in a brass tube with a blast of air in such a way that it would be blown or carried as a cloud against a fine wire gauze basket, Dr. Rudge was able to collect the static electrical charge upon the basket and to determine the presence of a charge upon the particles of dust, and also the nature of the charge. In this way he determined the type of charge which was generated by clouds of many different materials. As a result of these studies he discovered certain general laws which seem to govern the charge upon the particles of dust. These laws are as follows:

Law 1. Non-metallic elements give positively charged clouds when the finely divided material is blown into a cloud by a current of air.

Law 2. Metallic elements give negatively charged clouds when the finely divided material is blown into a cloud by a current of air.

Law 3. Solid acids and acid-forming oxides give positively charged clouds, and basic oxides negatively charged ones.

A few illustrations which may be of interest are given in Table XX.

TABLE XX.

Charges generated on moving dust particles.

Carbon	+	Zinc carbonate	—
Sulphur	+	Copper chloride	+
Aluminum	—	Sodium chloride	+
Iron	—	Potassium nitrate	+
Magnesium	—	Dextrose	—
Zinc	—	Dextrine	—
Aluminum oxide	—	Starch	+
Iron oxide	—	Flour	—
Magnesium oxide	—	Sand	+
Zinc oxide	—	Fine soil	+
Sodium carbonate	—	Lycopodium	—

As a result of these investigations Dr. Rudge made the following conclusions:

(1) Nearly all kinds of finely divided material, when blown into a cloud of dust by a current of air, give rise to electrical charges upon the dust and upon the air.

(2) The nature of the charge resident upon the dust particles depends upon the chemical characteristics of the material.

(3) In general, the charge obtained upon the dust is opposite to that associated with the "ion" of the same substance when in solution, i. e., strongly basic bodies give NEGATIVELY charged dusts, and the strongly acidic bodies give POSITIVELY charged dusts.

(4) In the case of salts the charge apparently depends on the relative strengths of the acidic and basic ions.

(5) Similarly constituted bodies give similar charges.

After making tests with another type of apparatus, Dr. Rudge[1] says:

[1] "A Dust Electrical Machine." Proceedings of the Cambridge Philosophical Society. 1912-1914, vol. 17, p. 249.

"The effects produced by this machine are very remarkable with dry dust and a dry atmosphere, as the dryness allows of a very fine state of division of the dust." This apparatus (fig. 24) consists of a chamber (A) in which the dust is raised by sending into it a current of air from the bellows. The dust is carried into the Chamber B. This consists of a brass tube about 25 x 5 cms. insulated from the rest of the apparatus by an ebonite plug (E). The dust escapes through O. Using this apparatus it was possible to obtain sparks up to 5 cms. in length while under certain atmospheric conditions "brush" discharges would fly from the tube. In very dry atmosphere the chamber B could be dispensed with, the tube leading from A serving as a collector. Sparks would fly from it when a rapid current of dust was passing through it. In all cases the air escaping from the apparatus was strongly charged. The charge upon the apparatus probably has a two-fold origin: (1) That due to the raising of the dust; (2) that due to friction of the dust particles against the walls of the tube.

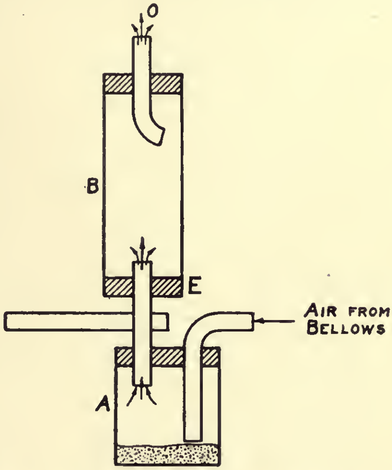

Fig. 24.
Device for Determining Charges of Dust.

In the raising of dust clouds the air as well as the dust became strongly charged. At first it was thought that the charge upon the air was caused by a similar charge being carried upon the particles of dust. However, it was shown[1] that the charge carried by the dust was the opposite of that carried by the air. That is, when a cloud of dust is raised into the air, thereby causing friction between the particles of dust and the air, static electricity is generated, the dust particles carrying a charge of one sign while the air becomes charged with electricity of the opposite sign.

The possibility that static electricity may be a cause of dust explosions was substantiated by early investigations of the Department of Agriculture of the cause of the large number of explosions and fires which were occurring in the threshing machines in the Pacific Northwest[2].

In these investigations it was found that the wheat crop in that section of the country, Southeastern Washington, Northeastern Oregon and Northern Idaho, was badly infected with a disease commonly known as stinking smut. When this wheat was threshed, the smutted heads were broken up in passing through the machine and the spores thrown into the atmosphere, forming dense clouds of smut dust. At the same time, threshing in atmosphere of very low humidity, large quantities of static electricity were generated and accumulated on the machines. The discharge

[1] Philosophical Magazine, London, Jan.-June, 1912, Vol. 7, No. 23, p. 852.

[2] Dust Explosions and Fires in Grain Separators in the Pacific Northwest. Dept. Agri. Bull. No. 379.

of this static electricity in the presence of the cloud of smut dust would ignite it and an explosion would result. Determinations which were made while the machines were in operation in the field showed that static electricity was generated on most parts of the machines, and under favorable conditions very high voltages were accumulated. In fact, the threshermen stated that often it was possible to pull 4- to 5-inch sparks from the driving belts and shorter ones from various parts of the machines. Measurements of the voltage present at many points gave indications that 50,000 volts, or even more, were not uncommon in very dry weather when threshing smutty wheat. Observations were made on a machine threshing alternately fairly clean and very smutty wheat. The amount of static electricity on different parts of the machine increased greatly in every case when the smutted wheat was threshed. This is in line with the work of Dr. Rudge and shows that not all of the static electricity is generated simply by the operation of the machine, but that some of it is caused by the dust created in the threshing process, and particularly by the smut dust.

In experiments made in the laboratory it was possible to ignite a cloud of smut dust by means of static electrical discharges generated in an ordinary Helmholtz machine. The Experiment Station of the State College of Washington conducted some tests upon the inflammability of smut dust. No trouble was experienced in igniting the dust with a free flame, and when a static electrical spark was substituted for the flame the smut-dust cloud was also easily ignited[1]. These are the first tests to show definitely that the static electrical discharge will ignite dust clouds, and that it is, consequently, an important factor in the cause of dust explosions.

It is a well-known fact that mixtures of gases can be ignited by means of an induction spark, which is very similar to a static electrical discharge from a Leyden jar. In fact, the induction spark is the type of spark used in firing the gas in automobile cylinders. But it is not so well known that gases can be ignited by an ordinary discharge of static electricity such as might be drawn from a moving belt. It may sound a bit exaggerated, but one of the authors knew of a person whose custom it was to light the gas at an ordinary fishtail burner in his room by the discharge, from his fingers to the burner, of the static electricity which was generated in his body by walking down the hall on a heavily napped carpet. At the Pittsburgh station of the Bureau of Mines no difficulty was experienced in igniting a Bunsen burner with the static electricity generated on a small drive shaft. This shaft was $1\frac{3}{16}$ inches in diameter and was driven by a 3-inch belt running at quarter turn over a $7\frac{1}{2}$ x $3\frac{1}{2}$-inch pulley. At the time of the tests only two of the nine $1\frac{1}{2}$-inch short belts which ran from the shaft to 3 small lathes on a bench beneath were in operation. The shaft was running at 360 revolutions per minute and under light load.

Copper wire fastened to the leveling bolt of a bearing at one end of

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[1] "Report on Fires Occurring in Threshing Separators in Eastern Washington during the Summer of 1914." Bulletin No. 117, pp. 10-11. Experiment Station, State College of Washington.

the shaft was attached to a small wood-handled file. When this file was brought close to an ordinary Bunsen burner, burning natural gas and grounded to a water pipe, sparks from ½ to ¾ of an inch in length were obtained. With the gas turned on, ignitions were always obtained when any discharge spark passed between the file and the top of the burner. The static electrical charge, especially noticeable on the shaft and belts on

Another view of the sugar refining plant in Brooklyn, N. Y., after the explosion in 1917, showing the extensive property damage.

days of low humidity, would persist on humid days following several dry days until the belts again became moist.

Dusts and gases are not the only substances which will be ignited by the static electrical discharge. It might be said that, under proper conditions, all finely divided material which will burn may be ignited by this source of heat. For instance, paper will take fire if held so that the discharges

of certain intensities pass through it. In connection with investigations made by the Bureau of Chemistry, and more fully described in a later chapter on Cotton Gin Fires, it seemed advisable to determine the possibility of igniting cotton with static sparks. At the beginning of these experiments, which were conducted co-operatively with the Bureau of Standards, observations of the nature of the sparks were made. As is well known, the ordinary discharge is bluish white, but upon inserting a resistance of several thousand ohms in series with the spark gap, the color became yellow. The effect of this resistance is probably to increase the duration of each individual discharge, and also to prevent the formation of a damped oscillating wave train of large amplitude for each spark. It was found that at slow-spark frequencies the ignition properties were quite independent of the resistance, while at frequencies of the order of 50 per second the use of the resistance rendered ignition easier.

It was observed that in the gap discharge one end produced ignition more readily than the other. Cotton could be held for an indefinite period at the positive end of the gap, but would ignite instantly when moved toward the negative terminal.

Gradually changing the length of the gap from 0.5 cm to 2 cm and thus varying the sparking voltage, while keeping the frequency and current the same, indicated that ignition was practically independent of the voltage. Keeping the voltage and capacity constant, but varying the gap current and spark frequency, it was found that there was a value of current beyond which burning took place with ease.

By maintaining a value of current slightly larger than the critical value for ignition at a given humidity and voltage with a high frequency, such as 100 sparks per second, and then decreasing the frequency by increasing the electrostatic capacity of the circuit, a frequency was found where ignition would no longer take place. Upon still further reducing the frequency (to about one spark per second), ignition again took place. This was observed only when using the series resistance.

Humidity is an important factor in determining whether cotton will ignite or not. At a relative humidity of 30 per cent a critical value of current was found to be about .125 mil-amperes, but at a room humidity of about 60 per cent, with the cotton kept as dry as possible and other conditions the same, a current of .23 mil-amperes was necessary.

The igniting properties of a static spark discharging between the balls of a sphere-gap were found (*a*) to be more pronounced at the negative than at the positive end; (*b*) at certain frequencies to be increased by a resistance in series with the gap; (*c*) to be independent of voltage; (*d*) to increase with the average current; (*e*) to vary somewhat with spark frequency, being less at an intermediate frequency, and (*f*) to decrease with increasing relative humidity.

In connection with the field investigations, described later, it was found that static electricity was present on parts of the cotton gin which were insulated from any rapidly moving machinery and which could not get any charge from other parts of the gin, as for instance the suction pipe through which the seed cotton is drawn from the farmer's wagon to the

cleaners. This pipe is usually made of galvanized iron and is insulated from the rest of the piping and the cleaner by a canvas joint. Often this pipe was heavily charged with static electricity which could have been caused only by the friction of the cotton upon the pipe. To determine that this was a fact and to find the sign of the charge so generated, a small laboratory equipment was arranged similar to the gin equipment. It is shown in Figure 25. The cotton was drawn by suction through the 5-inch upright pipe, through the horizontal pipe and against the screen located in a wooden box. The two sections of pipe were insulated from each other by the canvas joint and the screen was insulated from the pipe by the wooden box.

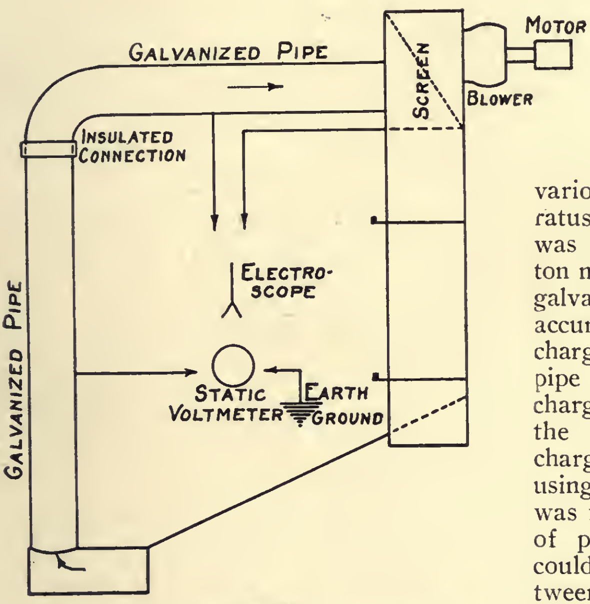


Fig. 25.
Apparatus to Determine Polarity of Static Electricity Developed by Friction of Cotton on Iron.

Using an electroscope, the sign of the charges on the various parts of the apparatus was determined. It was found that when cotton moves in contact with a galvanized pipe, the cotton accumulates a positive charge while the metal pipe becomes negatively charged. Upon striking the screen the cotton charges it positively. By using a static voltmeter it was found that a difference of potential of 800 volts could be maintained between the screen and the horizontal pipe. This is of particular interest since the apparatus was of a miniature size and was not working continuously. There was always a negative charge upon both pipes and a positive charge upon the screen, but when all three were electrically connected the charge was negligible. This would indicate that if it were possible to determine the sign and quantity of the charges on the various parts of the cotton gins, these parts could be connected electrically and the charges would largely neutralize each other.

From these tests it is very evident that static electricity may be generated in the operation of cotton gins, that a negative charge will be present upon some parts of the gin while a positive charge will be present on other parts, and that the discharge spark of this static electricity may be of such a nature as to ignite the cotton and start a fire.

That static electricity is generated in the operation of most industrial

plants is well known. Mention has been made of different places in the mills where it may be found. To get some idea of the quantities present, a series of tests was made to determine first the amount of the static electricity on belts, particularly large drive belts. These tests were made upon a 12-inch double leather belt, driven by a 21-inch pulley running at a speed of 500 revolutions per minute and operating a 48-inch pulley on a mill. The belt speed was approximately 2750 feet per minute. Among the determinations made were (*a*) the magnitude of the charges generated by the belt, (*b*) the variation in magnitude of the charges from various points on the belt, (*c*) the variation of the discharge with the increase in slippage of the belt, and (*d*) means of removing the charge from the belt.

(*a*) In determining the magnitude of the charges the apparatus shown in Figure 26 was used. This consisted of an electrometer with 6 condensers in series. Its capacity was approximately 50,000 volts. Charges

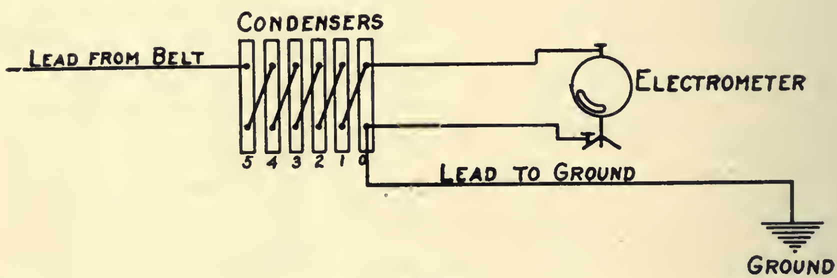


Fig. 26.
Apparatus to Determine Magnitude of Static Electric Charges.

ranging from 13,500 to 50,000 volts and above were often recorded, while in a few cases they exceeded the capacity of the measuring apparatus, probably being 60,000 volts or more. It will be noted that these are high voltages, and long discharge sparks may be produced.

(*b*) That the charge varied at different points on the belt is shown by the results given in Table XXI. The lead to the measuring apparatus was brought in contact with the belt at points A and F (fig. 27) where it comes in contact with the pulleys, and at points C, D and E along the belt.

It will be noted that the charge increased from points near the pulleys to a point midway between them, and then decreased as the belt approached the pulleys. Also, that where the belt came in contact with the pulleys the reading was zero, indicating that there was a ground somewhere about the machine through which a discharge was taking place. A possible course of this discharge was through the drive pulley, shaft, and step bearing in which the shaft revolves, to the frame and thence to a ground. If this were the case it would be necessary for the discharge to pass through the film of oil surrounding the shaft. This was possible with the excessive voltages recorded. However, owing to the construction

of the machine and installation, this point could not be definitely determined.

It was found that it was not necessary to bring the lead in contact with the belt before a charge was indicated upon the electrometer. In fact, a charge was indicated anywhere within 12 inches of the belt. The air all around the belt was charged by induction. The strongest field seemed to be approximately 3 inches from the belt. This is of interest in connection with dust explosions as a conductor somewhere near the belt might take up the charge from the belt and by conducting it to distant

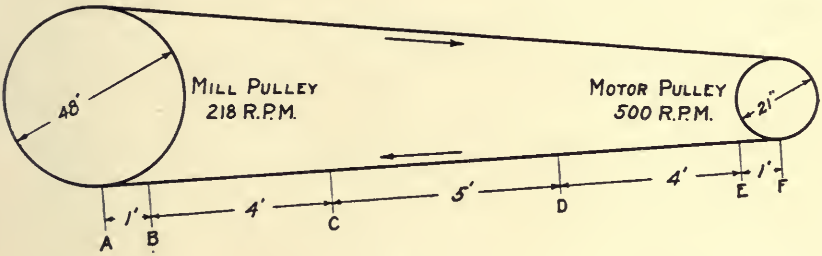


Fig. 27.
Location of Points of Contact on Belt in Static Electric Determination.

points cause discharges to occur at unexpected places. This would lead to a hazardous condition if a dust cloud were present where the discharge takes place. This may explain some explosions which start from unknown causes.

With no charge upon the belt at the points where it is in contact with the pulleys, questions arise as to where and how the static, which is present in such quantities on the belt, is generated and why it builds up as it travels away from the pulleys and decreases as it travels toward them. A partial ground may explain the lack of a charge at the pulleys and the decrease of the charge as the belt approaches them. Undoubtedly a large part of the static is the result of slippage of the belt, as will be noted

TABLE XXI.

CHARGE ON BELT.

Test No.	A	B	C	D	E	F
	Volts	Volts	Volts	Volts	Volts	Volts
1	0	23500	25500	25500	17250	0
2	0	19500	25500	25500	17250	0
3	0	21500	25500	27500	19500	0
4	0	27500	29750	27500	19500	0
5	0	19500	21500	21500	21500	0
6	0	21500	25500	27500	23500	0
Average	0	22166	25541	25833	19750	0

On May 22, 1919, a violent explosion of starch dust in a large factory at Cedar Rapids, Iowa, caused complete destruction of the plant. Forty-three lives were lost and property damaged to the extent of $3,000,000. Considerable damage was done to private and business property throughout the city.

later, but it seems reasonable to believe that some of it is caused by the movement of the belt through the air causing friction between the belt and the air. That the movement of large bodies through the air generates static has been noticed in the traveling of balloons. Several accidents have resulted from the ignition of the gases by static discharges from the bag to other parts of the balloon, and steps have had to be taken to so treat the fabric of the bag that static will be neutralized or dissipated into the air. This is usually done by coating the fabric with a material which will generate a charge opposite to that generated by the fabric itself. In the operation of aeroplanes static electricity has been generated and accumulated in such quantities on the machines as to seriously interfere with the running of the engine. Methods of neutralizing or dissipating the charge similar to those used upon balloons have been employed. Since these have been successful in preventing charges upon balloons and aeroplanes, a somewhat similar treatment of belts should prevent the generation and accumulation of static electricity upon them.

TABLE XXII.

STATIC CHARGES WITH VARYING TIGHTNESS OF BELT.

Operating condition of belt.		A	Magnitude of discharges at points: B	C	D	E	F
Loose	Maximum	0	27,500	29,750	29,500	19,500	0
	Average	0	24,800	27,600	28,200	18,800	0
Medium Tight	Maximum	0	23,500	25,500	25,500	17,350	0
	Average	0	20,800	24,800	24,800	17,200	0
Normal Tight	Maximum	0	17,250	19,500	19,500	19,500	0
	Average	0	16,600	17,400	18,000	16,200	0

(*c*) The generation of static electricity by belts has been attributed to the friction between the pulley and the belt. It would seem reasonable, then, to assume that with increase of the slippage of the belt on the pulley, the charge generated would increase. That this assumption is true is shown by the results in Table XXII, giving the charges generated (1) with the belt as loose as possible, (2) with the belt medium tight, and (3) with the belt running normally tight.

It will be noticed that at all points on the belt at which observations were taken, the magnitude of the charge decreased as the belt was tightened. This shows that slippage of the belt on the pulley does cause a large amount of the static electricity found upon belts. It also indicates, as suggested above, that slippage causes some of the charge found at points away from the pulley.

(*d*) Two devices for the removal of the static electricity from belts were tried. They proved to be quite efficient. The first consisted of a number of wires strung along the outside of the belt from one pulley to

the other, both above and below, and extending beyond the pulleys. (See Figure 28.) The wires were placed about 2 inches apart, ¾-inch from

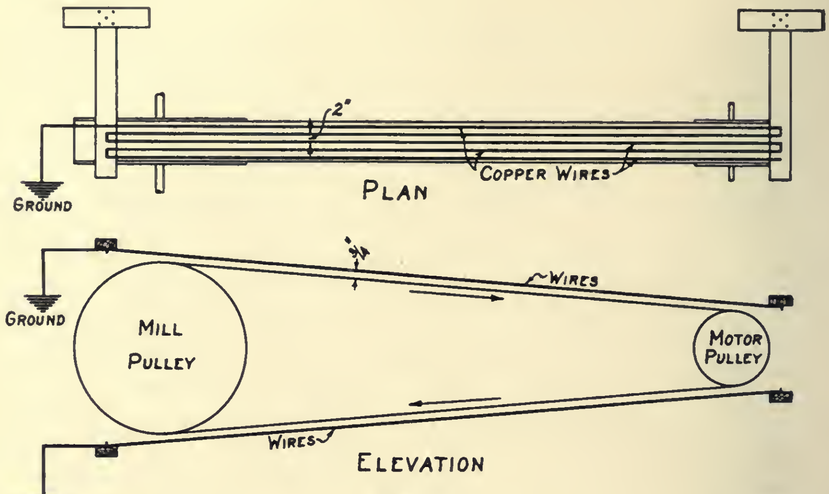


Fig. 28.
Wire Device for Removing Static from Belts.

the belt, and grounded to an iron guard railing. This installation was effective in removing the charge, as in repeated trials the electroscope indicated no charge on any part of the belt. With one set of wires removed, either above or below, a charge was found upon the other side equal to that measured when the belt was not grounded at all, and no charge was found on the side where the ground wires were left. Therefore, to remove the static electricity from the entire belt with such an equipment it would be necessary to have the grounded wires along the full length of the belt.

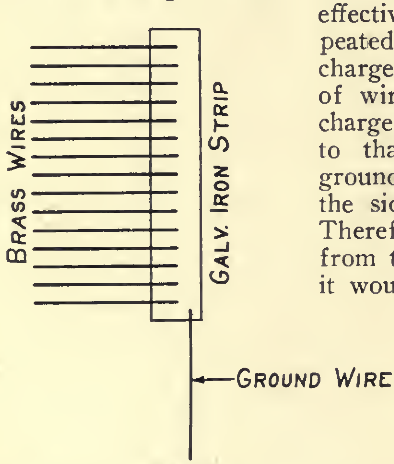


Fig. 29.
Comb Device for Removing Static from Belts.

The second device consisted of a number of wires, arranged like the teeth of a comb, rubbing on the belt and properly grounded. (See Figure 29.) The combs used in the tests consisted of strips of galvanized iron 12 inches x 2 inches to which were soldered pieces of spring brass wire, spaced about ¾ of an inch apart. This device removed the static electricity provided the combs were placed in the proper positions, namely, within a few

inches of the points where the belt leaves the pulleys. These points are indicated as *a* and *b* in Figure 30. With the combs at these two points no charge was found upon the belt, but with the combs placed at *c* and *d* as large charges were found on the belt as without the combs, except at points within a few inches of the combs. Also with only one comb at either *a* or *b* charges were found on the other side of the belt but

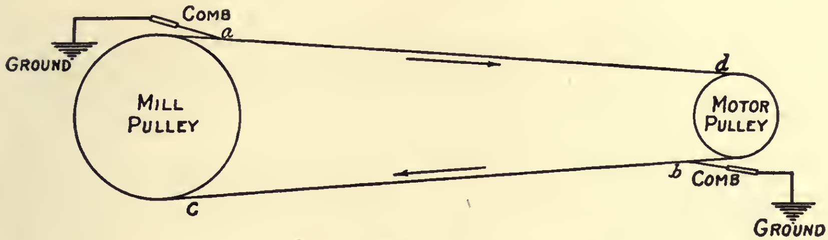


Fig. 30.
Proper Location for Combs.

not on the side where the comb was installed. It is necessary, therefore, that two of these combs be used for the removal of the static electricity, and that they be placed in contact with the belt within a few inches of the points where it leaves the pulleys. Such an installation is effective and is much simpler than the wire grid. However, care should be taken that the combs are kept in contact with the belt, especially if running in a gaseous or dusty atmosphere, as sparks will jump between the belt and the combs. These might ignite the gas or dust.

In August and September, 1919, another series of tests was made in mills and elevators in Seattle, Tacoma, Portland, Spokane and Minneapolis to obtain some idea of the points in the plants where static electricity might be generated and in what quantities. As no extended tests were made at any one place the effect of weather conditions could not be studied, but on account of the number of cities and mills in which tests were made the results as a whole should be indicative of what might be expected in normal operations.

Static electricity was found on practically all belts, the quantity depending upon climatic conditions and upon the size, material, speed and slippage of the belts. A maximum of 75,000 volts was recorded on a 22-inch main-drive leather belt running from an electric motor to a main shafting. The charge upon the belts was usually negative, but in two or three cases it was found to be positive.

Interesting results were obtained from tests made upon numerous conveyor belts, large slow-moving belts carrying grain. These ran at the comparatively slow speed of 750 feet per minute. Consequently, slippage and friction were practically negligible. In spite of this fact, 45,000 volts were recorded on one rubber conveyor belt carrying grain from the elevator head to storage bins. Wheat slightly smutted was being conveyed at the time. A similar belt in the basement, also conveying smutted

wheat, showed a charge of only a few hundred volts. No reason could be found for this difference except the possibility that the belt in the basement may have been partially grounded or that it may have been due to greater humidity in the basement. As the entire building was of concrete and steel construction, it is possible that some of the supports of the belt in the basement were in contact with iron which reached the ground. Then there is the possibility that the slightly smutted wheat became charged with static electricity during the process of elevation, and transmitted this charge to the conveyor belt above the bins.

High voltages were not found on the rolls, the feed rollers or on the grinding machines, but small charges were usually present. A similar condition obtained in the bran and shorts duster, while 2500 volts were found on parts of the scourers.

Small charges were found on fan casings, fan shafts, and on intake and discharge pipes, while charges of several hundred volts were measured on various points of cyclone dust collectors. Small charges were indicated on the discharge pipes of tubular dust collectors.

Small charges were found on the suction pipes of pneumatic unloading systems. However, it was stated by men working at these that on certain days, when wheat was being unloaded, and especially smutted wheat, very heavy charges were present.

At the time of the investigations the elevators were not operating continuously as very little grain was being moved. However, in those that were running, high voltages were found on all drive belts and small charges on the elevator legs and discharge spouts.

Although these results are not as conclusive as could be desired, they indicate that static electricity may be generated in nearly all parts of mills and elevators, and that it often accumulates in such quantities as to make operation very hazardous. Apparatus was not available to determine the amperage of the discharges from the various machines, so it is not possible to say whether these discharges would, or would not, ignite the dust. As was noticed in the case of cotton, the two things which control the igniting power of the discharge are the frequency and the amperage of the discharge. These doubtless vary under different operating conditions, so that it is possible to have discharges which will not ignite the dusts. But so long as there is a charge which has sufficient voltage to make a discharge spark, a dangerous condition exists. The results of the investigations referred to indicate that sufficient voltage may be generated under certain conditions in most mill equipment.

Static electricity is an important factor to be considered in relation to dust explosions, and that it has been the cause of some explosions has been proved by experiences in certain mills. A disastrous explosion occurred in a starch factory in New Jersey, in September, 1914, which seemed to be caused by static electricity. The explosion had its origin in a dextrine reel, and is believed to have been started by a discharge of static electricity generated by the friction of dextrine particles on an 80-mesh brass gauze screen surrounding the reel. The reel was revolving at 16 revolutions per minute. Several years before when similar

explosions had occurred in the same type of reels, the officials of the company concluded that they had been caused by the static electricity developed in the reels by the friction of the fine particles on the screen. The reels were then grounded by a connection from the journal box at one end to the pipes of the sprinkler system. No further explosions were experienced after the grounding until the one in 1914. A short time before this explosion the ground wiring had been inspected and seemed

An explosion of aluminum dust in a plant at Manitowoc, Wis., on February 26, 1920, resulted in the death of 6 girls and injuries to a number of others. Note, extending from the fan exhaust at right of picture, a piece of heavy wire that in some unknown manner was introduced into the fan thereby producing the necessary spark to ignite the aluminum dust. The girl operators were occupying the chairs at the work bench shown in the picture.

in good condition. Just a few minutes before the explosion the bearing had been oiled, which would indicate that there was a heavy film of fresh oil surrounding the shaft, insulating it from the bearing. Oil of this type offers a resistance to the passage of an electrical charge equal to 10 times that of air. This film of oil may have insulated the reel sufficiently to have allowed static electrical charges to accumulate on the reel, the discharge of which may have ignited the dust in the reel and started the explosion. That the installation of a thorough ground with a dry brush

This picture shows concrete bins completely destroyed by the explosion in the North Western Elevator, South Chicago, Ill., on March 19, 1921. This elevator had a capacity of 10,000,000 bushels and was regarded as a model both for construction and mechanical equipment installation. Six men, the entire number at work in the elevator at the time of the explosion, were killed and property and grain damaged to amount of $3,750,000.

contact to the shaft of the reel and the connection of all metal parts of the reel to the shaft have been effective in removing the static electricity from these reels is shown by the fact that no explosions have occurred since the reels were equipped in this manner, a period of seven years.

An explosion in the starch grinding department of the same mill a few months later was traced to a starch reel. The ground wire leading from one of these starch reels appeared to have been broken some time prior to the explosion. This would have allowed the static electricity to accumulate in the reel and its discharge within the reel to ignite the dust. No explosions have occurred in these reels since they were thoroughly grounded by the dry brush contact to the shaft.

A mill in Texas, in which cotton-seed oil cake was crushed, experienced trouble from explosions in the hammer type grinding machine. This machine consisted essentially of two parts, an outer case and a revolving horizontal cylinder. The case had a large opening in the top for the admission of the material to be ground, and a large semi-circular opening at the bottom covered over by a set of grate bars. The cylinder included a shaft to which several sets of flat, steel, hinged bars or hammers were attached. In operating the machine, the cotton-seed cake, fed into the opening, was beaten by the rapidly revolving hammers and forced through the grates, thus crushing it into comparatively small pieces. These dropped into a pit underneath the machine. The cylinder ran at a speed of 1000 revolutions per minute. Two explosions occurred in one of these machines shortly after it was installed. Although they were not particularly violent or destructive the force was sufficient to blow apart the casing of the elevator legs, and the flame, coming out into the mill, burned some of the employees.

At first it was thought that foreign material—bolts, nuts or nails—had gone into the machine with the cake and created sparks which ignited the dust. Previous experience, however, showed that this was hardly possible, as there had been no unusual noise preceding the explosion. After all the circumstances had been carefully considered, the conclusion was reached that static electricity, generated in or around the machine, resulted in a spark which ignited the dry dust formed inside the mill. It was thought that the slippage of the belt on the pulley every time a mass of cake was fed into the machine generated static electricity which accumulated in the rotating shaft. This shaft appeared to be insulated from the casing by the film of oil in the bearings. When the charge became large enough to break down the resistance of the air within the machine, a discharge spark was produced. Unquestionably this accumulating and discharging goes on almost continuously at times, and many sparks are produced which do no damage, either because there is not a proper mixture of dust and air, or because the discharge is not sufficiently intense or frequent. But when the discharge sparks continue to be produced in large numbers conditions for an explosion may be present at any time.

These machines were grounded by attaching a heavy copper wire securely to the casing and soldering the other end to an iron rod driven

several feet into moist earth. Since grounding the machines several years ago no explosions have taken place. This indicates that static electricity must have been the cause of these explosions.

That static electricity is a cause of fires and explosions in grinding machines is proved further by the experiences of other mills. A large cereal plant in Oakland, Calif., was troubled with numerous fires in two attrition mills, even though they were equipped with magnetic separators. These fires continued with regularity for several months, and no cause could be found. Steps were about to be taken to remove the machines when the mechanical engineer of the mill thought of the possibility of static electricity as the source of trouble. The machines were grounded by means of a brush contact to the shaft and by a connection to the frame, the ground wire leading to a water pipe. The fires did not recur, and no further trouble has been experienced.

Even more convincing is the experience of the Sperry Flour Company at their plant in Stockton, Calif. Within a week seven explosions occurred in an attrition mill used for grinding oat hulls into feed. Most of these were not particularly violent because the system of handling the feed from the mill was so arranged that they would be vented to the outside. However, in one case, the elevator leg was badly damaged, and the safety vent pipe and head of the elevator were blown off. It is probable that this would have propagated to a disastrous explosion if the mill had not been exceptionally clean.

The attrition mill in which the explosion occurred was of the ball-bearing type, driven by direct connected induction motors. The oat hulls coming to the mill were separated from the groats by an air blast, the heavier groats falling into a bin while the lighter hulls were carried on into a chamber from which they were spouted to the mill. This gravity separation precluded the possibility of heavy foreign material being carried over with the hulls and getting into the grinding machine. This made it necessary to look for some other cause for the explosions.

The miller thought that static electricity might be the cause and went to some trouble to prove that it was. A gold-leaf electroscope was procured and various parts of the particular mill were tested. Violent positive deflections were noticed from the frame, and none at all, or what the miller thought were negative deflections, from the shafting. This was an indication to him, but it was not conclusive, so he cut out a piece of the plate housing of the mill and inserted glass through which he could watch the inside of the mill. At the instant of the most violent explosion the miller was watching sparks jump from the grinding plates of the mill. The sparking was intermittent at first and then continuous. At the time when the sparks seemed to be streaming around the outside edges of the grinding plates the explosion took place in the mill and elevator leg. The miller noticed particularly the color of the sparks or "fire," and described them as light blue, the characteristic color of the discharge spark of static electricity. Sparks caused by friction are very different, being yellow in color, and there is no trouble in distinguishing between them. Steps were taken immediately to ground all the attrition

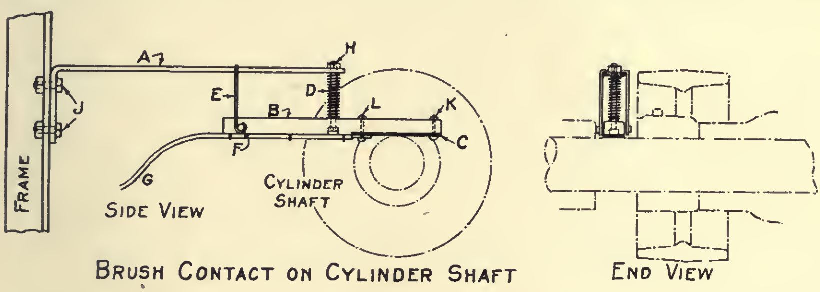
mills in the plant. The trouble ceased, and no explosions have occurred since that time.

So far as known, this is the only case where a man has not only actually seen an explosion start within a machine, but has been able to see the cause or the conditions immediately preceding the explosion. It would seem that no longer can there be any doubt of the fact that static electricity is a cause of explosions and fires in grinding machines.

In order to prevent explosions from static electricity it is necessary to prevent the generation and accumulation of the charge. This may be done by conducting away the charge as rapidly as it is formed or by neutralizing it at the point of generation.

Reference has already been made to two methods for conducting away the static electricity from pulleys and belts, one the series of wires strung along the outside of the belt and extending beyond the pulleys, and the other the comb of wires held in contact with the belt. Where these have been installed and properly grounded they have been effective.

For removing the charge from a shaft, as for instance in a reel or grinding machine, a dry-brush contact has proved very successful. This is much more effective than a connection to the bearing because the oil

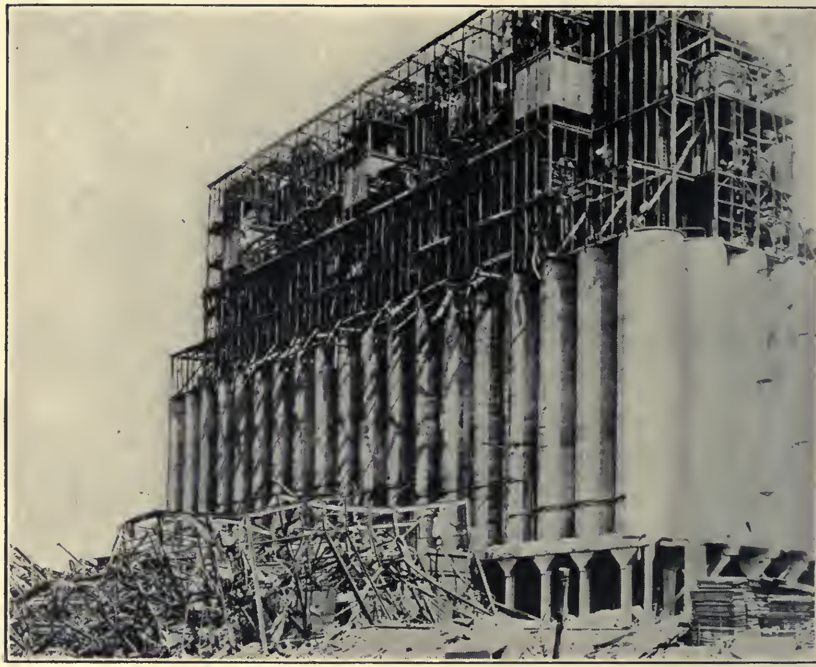


BILL OF MATERIAL

	No. Pcs Req'd	Name	Size	Material
A	1	Bracket	¼" x 1"	W. I.
B	1	Brush Holder	10" x 1" x ¾"	Hard Wood
C	1	Brush	3" x 1"	Copper
D	1	Brush Spring		Steel
E	1	Wire Support		
F	1	Fulcrum Pin	¼" x 1½"	W. I.
G	1	Lead to Ground-Insulated	No. 14 G	Copper
H	1	Spring Bolt	¼" x 3"	
J	2	Machine "	⅜" x 1"	
K	1	R.H. Stove "	⅛" x 1"	
L	1	" " " "	⅛" x 1¼"	

Fig. 31.
Brush Contact on Cylinder Shaft for Removing Static.

will often act as an insulator and prevent the charge passing from the shaft to the bearing and on to the ground. A simple device to act as this dry brush is shown in Figure 31, together with specifications in tabulated form. It consists chiefly of a copper brush held in contact with the shaft by means of a small coil spring. A wire connects the copper brush and the ground. A brush of this type can be made to fit any size cylinder or machine by changing the shape and size of the bracket A, which holds it in place. It will be noted that the copper brush can be



View showing damage to upper portion of work house as a result of explosion in North Western Elevator, South Chicago, Ill., March 19, 1921. The plant, although constructed entirely of steel and concrete, was completely wrecked.

replaced easily when it becomes worn out, but that the coil spring holds it in contact at all times until worn out. This device, developed primarily for use on threshing machines, has proved of value for use in industrial plants, being very effective in removing the static electricity, providing it is well grounded.

Another type of wiping contact to remove the static electricity from pulleys is a loose chain which hangs on the shaft, but with a collar on the end of the shaft so that it cannot come off. This chain is then connected to a ground. Unless oil works out from the bearing along the shaft, covering the chain, this type of contact is quite effective.

Care must be taken with any equipment which is installed to conduct away static electricity, to see that a good and thorough ground is obtained. Unless well grounded the charge will be stored up, creating a dangerous condition. Under normal conditions a water pipe from a city supply makes a good ground because the piping is extensive and usually some part of it is well grounded. It is advisable to make at least two and preferably three ground connections, so that the breaking of one wire will not cripple the system and make it ineffective. The simple fact that a pipe or rod is in contact with the earth does not mean that it makes a good ground. The earth at that particular point may not be a good conductor or may even be charged with electricity so that instead of removing one hazard, another is introduced. Such even may be the case with water pipes which are sometimes affected by stray currents from electric railways or other sources of electricity. Therefore, in installing the grounding system to remove the static electricity from any part of a plant these factors should be considered and tests should be made to assure an effective ground.

As has been stated above, static electricity can accumulate only when the humidity of the atmosphere is relatively low. When it is high the static electricity will be dissipated into the air as fast as it is generated. Advantage of this fact has been taken in developing systems for the removal of the static charges by artificially humidifying the atmosphere. This has been practiced especially in the cotton industry as in the operation of cotton machinery considerable static electricity is developed. To dissipate this and thereby to facilitate operating conditions systems of humidification were developed. These have also proved of great benefit in preventing fires in cotton mills[1], particularly those in the picker room. Incidentally, this is another proof of the fact that static electricity is the cause of many fires and explosions. This experience in humidification of cotton mills has led to the suggestion that it be practiced in other types of industrial plants where inflammable dusts are produced, as a means of prevention of explosions. In rare cases this might be advantageous, but the disadvantages in most cases would be greater than the advantages, and the expense of maintenance would be very high compared to the protection obtained. Humidification properly controlled and maintained will prevent the accumulation of static electricity and remove the hazard which it creates, but it cannot be economically applied in all industries. An equipment known as an electrical neutralizer has appeared on the market in recent years. Ordinary electric current is transformed into high frequency alternating current of high voltage and then passed through an apparatus known as an inductor, which is placed near the point from which it is desired to remove the static electricity. It is claimed that air around the inductor is charged with equal amounts of positive and negative charges and that any charge of static electricity which may be generated will immediately be neutralized by the opposite charge created in the air by the neutralizer. The authors have not tested out this equip-

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[1] "Humidity a Factor in Cotton Picker Fires," F. J. Hoxie, Quarterly National Fire Protection Assn., vol. 9, p. 399.

ment and are therefore not in a position to pass upon it. However, several letters have been received from industrial plants where it has been installed in which statements are made indicating that it has been effective in neutralizing the static electric charge as fast as it is generated. If it will do all that is claimed for it, a long step forward has been made in the prevention of the hazards of static electricity. It is

Damage to bin foundations in river house by explosion at North Western Elevator, South Chicago, Ill. The pressure built up was sufficient to crack the solid concrete construction in both the bins and foundation walls.

at least based upon the correct idea of removing or neutralizing the charge as fast as it is generated, and not allowing it to accumulate.

It has been shown that static electricity is a hazard in industrial plants, particularly where inflammable dusts or gases are present. Not every individual discharge of it will ignite a dust or gas mixture, since the ignition depends upon the nature of the inflammable material the amount of it which is mixed with the air at the point of the discharge, and upon the nature of the discharge. Even with the most inflammable mixture, an ignition may not result from the discharge spark, for its igniting power depends upon the amperage and the frequency of the discharge. These factors have been roughly determined for cotton, but not for gases and dusts. However, since these substances are much more finely divided

and have more surface exposed, it is to be expected that they may be ignited by discharge sparks of lower amperage and frequency. Even the sparks which will ignite cotton may be easily generated in industrial plants. Consequently it is very important that steps be taken to remove the static electricity as fast as it may be generated, and not allow it to accumulate.

CHAPTER VIII.

EXPLOSIONS IN GRAIN THRESHING MACHINES.

It must not be concluded that dust explosions and resulting fires are confined entirely to industrial plants where explosive dusts are created during the operating processes. Disastrous losses have resulted from explosions and fires during the handling, threshing and harvesting of grain, in certain grain growing sections of the United States.

In the Pacific Northwest the wheat growing sections of Eastern Washington, Northern Idaho and the adjoining territory in Northeastern Oregon have experienced extensive losses from these dust explosions and fires[1]. Similar occurrences have taken place in other sections of the West and in some instances reports have been received of explosions of this nature in some of the eastern and southern states. In one season alone in the Pacific Northwest as many as 300 of these explosions and fires occurred resulting in upwards of $1,000,000 loss. For a number of seasons the losses ranged from $15,000 to $75,000 in machinery and grain destroyed by explosions and fires in grain threshing machines.

Frequency of Explosions.

The conditions under which these explosions occurred appear somewhat similar to those of other cereal dusts. During threshing operations the wheat smut[2] dust, which is very fine and powdery in form, is thrown into suspension in the air around the cylinder and other parts of the machine and forms a mixture which can readily produce an explosion and fire if ignited. This mixture of smut dust and air may have limits of explosibility similar to the gas mixtures, and it is quite possible at certain times to have too much dust present, and at other times not sufficient to form an explosive mixture. For this reason explosions may occur at given times under certain conditions and not occur at other times under somewhat similar conditions.

Inflammability of Wheat Smut Dust.

Reference has already been made in Chapter 1 to the tests conducted by the Bureau of Mines in which explosions were produced when there was only 0.32 oz. of coal dust suspended in each cubic foot of air. It was

[1] United States Department of Agriculture Bulletin No. 379—Dust Explosions and Fires in Grain Separators in the Pacific Northwest.

[2] Smut is a cereal disease, Tilletia Tritici—commonly known as "stinking smut."

found that in order to produce complete combustion it takes all of the oxygen in one cubic foot of air to burn completely 0.123 oz. of coal dust used. Tests by the Bureau of Chemistry have shown that smut dust is highly inflammable and also that many of the cereal dusts have relatively lower ignition temperatures and produce higher pressures than coal dust. It could therefore be reasonably concluded that the explosive limits of cereal dusts would be lower than those of coal dust.

In some of these thresher explosions two reports were heard. Such explosions are similar in nature and action to dust explosions in industrial

Remains of threshing outfit after dust explosion and fire. These explosions cause extensive damage to machines and grain.

plants. The first report is usually short and quick while the second resembles a loud roar lasting longer than the first and accompanied by more flame. An explosive mixture consisting of sufficient quantity of smut dust in suspension, ignited by the proper source, would no doubt cause the sharp report usually heard first. This original ignition would probably produce sufficient concussion to shake into the air the dust that had settled in various parts of the threshing machine, thus forming an additional explosive mixture. The heat or flame from the first small puff would cause an ignition of this newly formed mixture and the explosion would propagate through the entire dust zone in the same manner that explosions travel in industrial plants. This may serve to explain the loud rumbling sound sometimes heard, and the large body of flame that causes extensive damage.

Origin of Explosion.

Over 75 per cent of the explosions of this nature in grain threshing machines originate back of the cylinder or very near this point, indicating

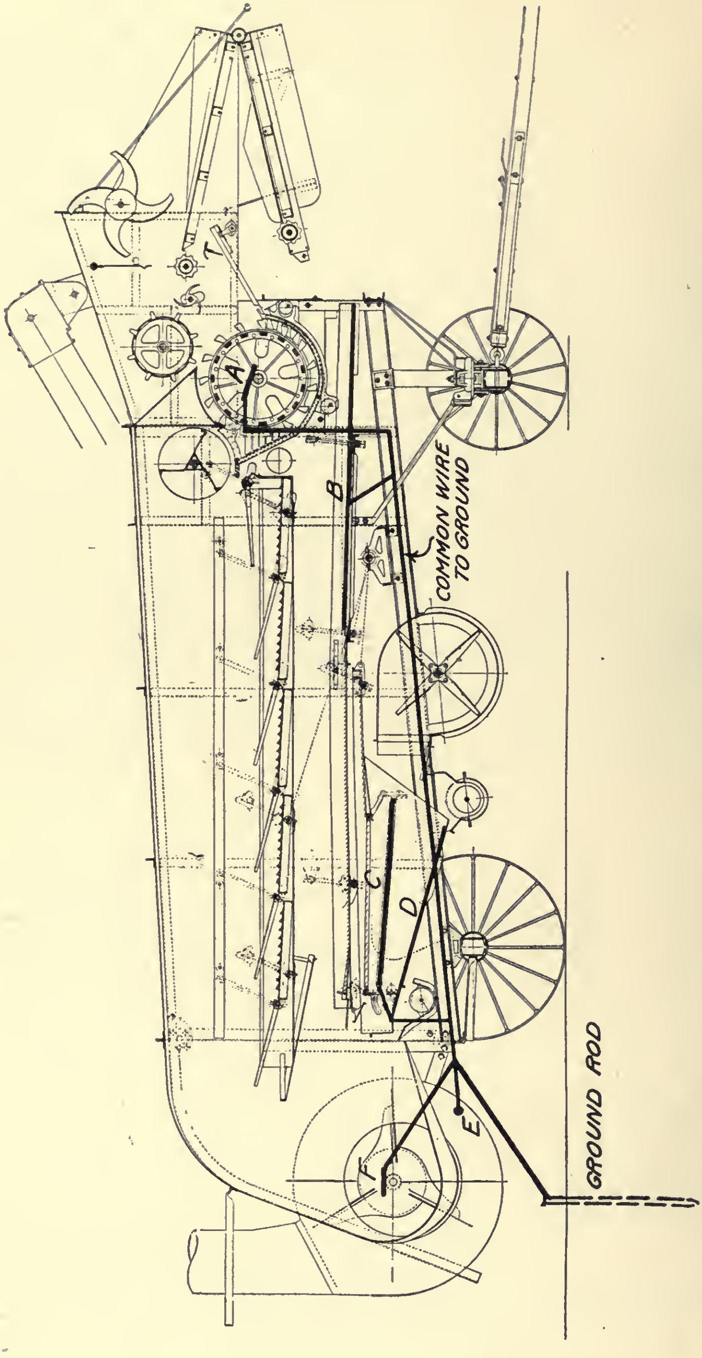


Fig. 32.
Wiring Diagram for Grounding Threshers.

that the source of ignition in the great majority of cases was near this part of the machine. Although local opinion, as is usually the case in new developments of this character, was inclined toward incendiarism, thorough investigations have shown that the occurrences are accidental in nature and caused in a large degree by the quantity of smut in the wheat and the very favorable climatic conditions in the territory affected. The experimental work by the U. S. Department of Agriculture conducted in the field and later at the Arlington Experimental Farm, Arlington, Va., showed that under ordinary operating conditions it is very difficult to secure a fire in a grain threshing machine by the introduction of matches or other foreign materials. In some of the experiments, in order to set fire to the machine it was necessary to introduce a flame and to secure positive results, use was made of waste and rags soaked in gasoline and ignited by a flame from the outside. Bundles of matches fed in with the straw did not cause a fire.

The explosions occurred in all makes and types of threshing machines regardless of their size and mechanical operating features, but were most frequent during the threshing of wheat containing large percentages of smut dust. The damage to the machines varied from slight damage to total destruction. In cases where fire fighting equipment had been provided, the damage naturally was much smaller than in cases where no precautions had been taken. In many instances the flame from the explosion and fire was blown into the straw pile and spread to the stacks of grain and also the unthreshed part of the field, resulting in some cases in the destruction of several hundred acres of grain.

Static Electricity.

The investigations of thresher explosions have indicated very definitely that static electricity was responsible for a large number of these occurrences. It was very evident in the beginning of the investigations that a large quantity of static electricity was generated in a variety of ways during the operation of the separator. It may be generated by the friction produced by the rubbing of metallic parts, or by the slipping of belts on pulleys, or it may result from the rubbing of grain, straw and dust against the metallic surfaces of the machine. By means of equipment especially designed and constructed, high voltages have been recorded, and it has been found that static electricity is present in large quantities at certain periods of the day while the machines are operating. Data obtained in these investigations have assisted in the development of effective methods for the control of static electricity around threshing machines and have also been valuable in working out methods for similar control in industrial plants.

Grounding Methods.

Considerable work was done in developing satisfactory grounding methods for the control of static electricity. The work was conducted along three distinct lines: First, separately grounding each part and each

shaft, the latter either directly or through its bearing; second, connecting wires from all affected parts to one conductor and grounding that conductor; third, wiring all affected parts to some metallic portion of the separator of sufficient magnitude to act as a ground. The first method was the most common among the thresher operators, although the second method was the one which the Department investigators mainly advocated. One of the wiring systems devised for grounding static electricity is shown in Figure 32. A study of this sketch will show that the common wire or conductor is grounded through a rod which should be driven in the ground at least three feet. There is a connection, A, to the common conductor from the shaft of the cylinder through the copper brush which is shown in Figure 31. This brush is in contact with the shaft itself and not in contact with the bearing. This construction is used to avoid any possibility of insulation due to the film of oil between the shaft and the bearing. The grain pan is connected to the lead, B. The lead C, which extends over the shoe sieve, connects that part of the separator to the common ground wire. The shoe screen is connected to the lead D. The lead E connects the metal casing of the stacker fan to the common ground wire. The stacker fan is connected to the common ground wire through the copper brush at F. This is the same kind of brush shown in Figure 31 which is also used to ground the cylinder shaft. It should be remembered that the best results are obtained by connecting the brush to the stacker fan shaft rather than just grounding the bearings of the stacker fan. The investigations in the field indicate that the moving parts just described are the ones on which static electricity is likely to be generated. These investigations also show that there were occasional collections of static electricity on the metal casing. For this reason that connection was made. The common lead wire and its main branches are of No. 14 copper wire.

Blower Fans.

Special dust collecting fans designed by the United States Department of Agriculture[1] for the prevention of grain and smut dust explosions and fires in threshing machines have been found to be effective in: 1. The prevention of explosions and fires in threshing machines, by collecting the dust from the interior of the separators, thus preventing the formation therein of explosive mixtures of smut and grain dust and air. 2. The cleaning of grain, particularly of smut, as an economic feature in grain handling because of its effect on the grading of wheat under the Federal standards. 3. The control of the wind dissemination of smut spores. In addition these fans materially improve working conditions about the machine. Such fans should be installed on as many grain separators as possible, particularly in the Pacific Northwest, and in all other grain growing sections where bunt or stinking smut of wheat is prevalent.

[1] United States Department of Agriculture Circular 98—"The Installation of Dust Collecting Fans on Threshing Machines for the Prevention of Explosions and Fires and for Grain Cleaning."

It is impossible to give detailed specifications of a fan installation adaptable to all types of grain separators, because of the peculiar and characteristic construction of the various makes of threshing machines. Special attention should be given to many important features in the selection and installation of dust collecting fans. Extensive investigations and experiments have shown that to be most effective and satisfactory such equipment for threshers should embody as many as possible of the following general points of design and construction:

1. A centrifugal type, steel plate exhaust fan is most desirable.

2. A single-inlet type fan has the advantage of offering the least obstruction to the deck. The fan casing should be volute or spiral.

Explosion of wheat smut dust in threshing machine in Pacific Northwest.

3. The fan drive should be as direct as possible from the cylinder shaft. The fan pulley should be as large as is practicable to prevent undue slippage of the belt. A minimum diameter of 4 inches is recommended.

4. A light running fan of simple but rigid construction securely attached to the frame of the separator answers the purpose best.

5. Ample exterior bearings should be provided with no overhang of the shaft.

6. The fan should have a peripheral speed of approximately 6500 feet per minute, with a capacity, under field conditions of from 35 to 40 cubic feet of air per second for medium sized machines, ranging from 26 by 46 inches to 32 by 54 inches. The above values would be slightly greater for a larger machine and slightly less for a smaller machine. The revolutions per minute of different size fans may be varied to obtain the constant peripheral speed suggested. Based on these figures, a fan

of regular size—21 inches in diameter from tip to tip of vanes—should run at a speed of approximately 1200 revolutions per minute. The same results could be secured with a larger fan operated at a lower speed or with a smaller fan operated at a higher speed. The smaller fan of course has the advantage of occupying less space. The air resistance of such a fan operating under general threshing conditions would be a pressure of approximately two ounces per square inch.

7. The eye or inlet of the fan should be located opposite the fan pulley at the center of the casing. The discharge pipe should have an area at least as great as that of the inlet.

8. To collect dust and other foreign material from the separator most effectively without removing the heavier particles, a fan must handle or remove a large volume of air with a very gentle movement at the intake, the velocity of the air increasing as it approaches the inlet or eye of the fan. This condition is produced by means of a tapered intake of large area at the base.

9. The intake hood should be tapered and the intake should cover a deck area of not less than 600 square inches.

10. The intake should be centered and placed at a forward position on the deck. On most machines this location would be over the beater.

11. If straw, grain, or other heavy material is thrown upward into the fan intake by the beater or cylinder of the separator, it will be necessary to place a deflection plate or baffle board, preferably metallic, under the intake at an angle of approximately 30° with the deck.

12. The absence of sharp, abrupt curves or bends in the intake and connecting parts is most important. Elbows of all piping should have an ample sweep or radius. If possible, no turn in an air pipe should be made with a radius of less than twice the pipe diameter.

13. The least possible obstruction should be offered by the fan equipment to the deck and to the interior of the machine through the deck doors.

14. The fan discharge should be conducted through a metal pipe to the rear of the separator; thence by a canvas tube into the base of the straw stack. Such an arrangement greatly reduces the wind dissemination of, and subsequent soil infestation by, smut spores which otherwise would be blown into the air.

15. If two or more discharge pipes are united, the cross-sectional area of the final common pipe should be approximately equal to the combined cross-sectional areas of the original pipes. Otherwise the efficiency of the fan is greatly impaired.

Types.

At the suggestion of the United States Department of Agriculture, various threshing machine companies have manufactured and installed special fan equipment on numerous machines operating principally in the Pacific Northwest. Figure 33 shows one of a number of effective and satisfactory types of these fans. This fan is driven directly from the cylinder shaft at a speed of 1000 revolutions per minute. The whole

equipment is well constructed and rigidly attached to the separator frame. The two intakes, one over the cylinder, the other above and just back of the beater, should be noted. A metal deflection plate placed directly under the front intake, at an angle of about 30° with the deck, prevents the cylinder from throwing into this intake any straw, grain, or other heavy material. This fan removes large quantities of dust, mainly

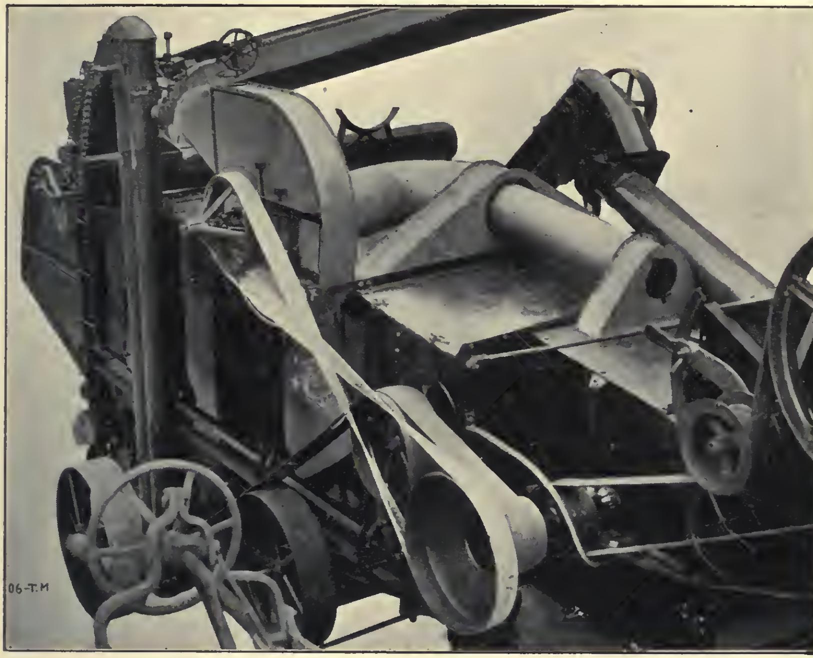
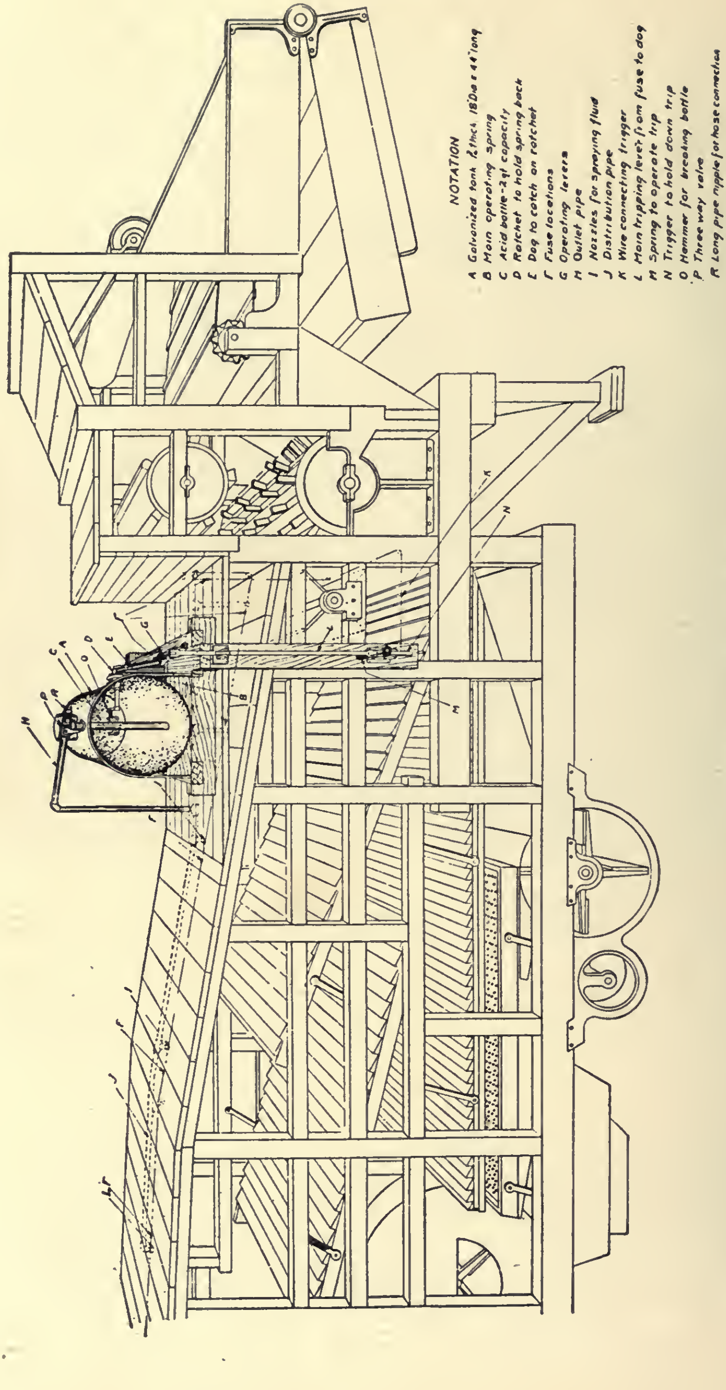


Fig. 33.
Effective Fan Installation on Threshers.

through the rear intake. The equipment would no doubt be more efficient if the front intake were eliminated, the rear intake enlarged and moved slightly forward and the intake hood built along pyramidal lines, with no sharp abrupt curves.

Extinguishing Systems.

There is always the possibility that explosions and fires in grain separators may be caused under certain conditions by sparks resulting from the entrance into the machine of foreign materials and by hot boxes. Although the results with fans and grounding systems have been satisfactory, effective fire extinguishers adapted to threshing machines afford additional protection irrespective of the cause of the explosion or fire. A



AUTOMATIC FIRE EXTINGUISHER.

Fig. 34.

Typical Installation of Automatic Fire Extinguisher.

successful extinguisher must be capable of spraying the entire interior of the machine instantly. Investigators of the U. S. Department of Agriculture endeavored to determine the relative efficiency of the several types of sprinkler systems and fire extinguishers in use. It was found that there were many different types and patterns of sprinkler systems in general use throughout the territory, but they were almost all included in three different classes[1]:

1. The chemical fire extinguisher.
2. Water with (a) air pressure, (b) steam pump compression.
3. Hose or pipe from boiler to separator.

Chemical Fire Extinguishers.

The chemical fire extinguishers consisted essentially of a suitable tank approximately two-thirds full of water charged with sodium bicarbonate, a bottle containing sulphuric acid placed either within the tank or in a small chamber supplementary to it, a tripping device either to upset the bottle or to break it, and a system of slotted pipes placed under the deck. The chemical extinguishers adapted to threshing machines are represented by two types, classed as non-automatic and automatic. With the first type the bottle of acid is upset or broken by the action of a plunger connected to a lever operated by hand. The second type differs from the first in that the operation of the plunger and lever is controlled by a systematic arrangement of fusible links, wires and springs.

An automatic extinguisher designed in the Bureau of Public Roads and Rural Engineering of the U. S. Department of Agriculture is shown in Figures 34 and 35. A full sized working model of this extinguisher was constructed and tried out in the explosion galleries of the Bureau of Mines at Pittsburgh, Pa., and also on four representative types of threshing machines at the Arlington Experimental Farm. In a total of 27 tests the extinguisher operated satisfactorily, and in no case did it fail to operate automatically and properly and to extinguish the fire before any damage was done.

The automatic extinguisher consists of the following parts: Tank (A) mounted on top of the machine; within the tank a bottle (C) containing sulphuric acid; a discharge pipe (H); a tripping mechanism composed of operating levers (G) and main tripping lever (L); a trigger (N); discharge nozzles (I); and fuses (F) mounted in a wire line. In the discharge line between the tank and the machine may be mounted a three way valve (P) from which there may be led, as at (R) a hose connection for extinguishing outside fires. The tank is filled with water containing soda and the extinguisher operates as follows:

The presence of sufficient heat within the machine will melt one of the fuses (F). This breaks the wire line, releasing the trigger which frees the tripping mechanism, causing a hammer within the tank to strike a blow sufficient to break the bottle. The discharge of the sulphuric acid

[1] United States Department of Agriculture Bulletin No. 379—"Dust Explosions and Fires in Grain Separators in the Pacific Northwest."

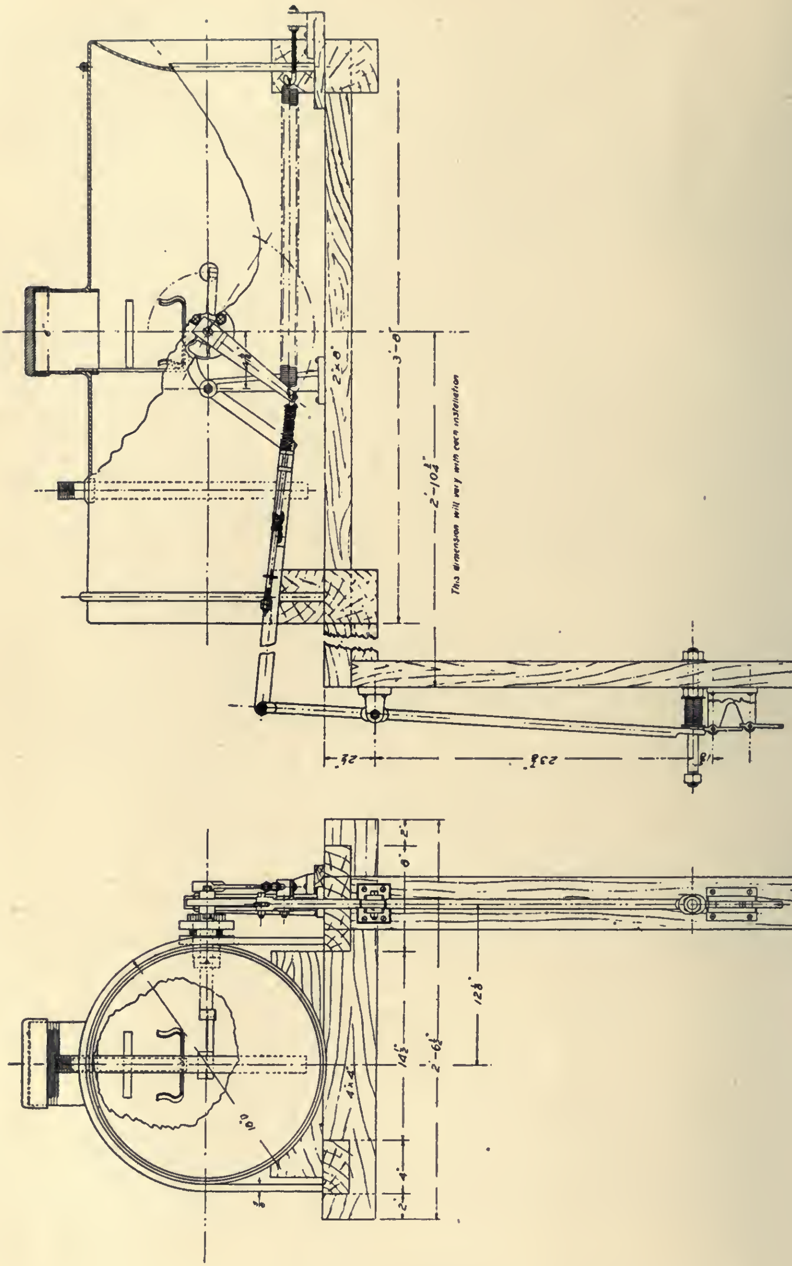


Fig. 35.—Assembly of Automatic Fire Extinguisher.

into the water containing soda causes the formation of carbon dioxide, which generates sufficient pressure to force the water through the discharge pipe and the nozzles to all the crevices of the machine.

The location of the fuses (F) shown in the figure are those suitable to the particular type of machine shown in the drawing. The locations, however, will vary with each machine, and must be selected so that the fuses are sure to be reached by the flame or the heat, but not so placed that the wire connecting them is likely to be broken by the straw or the moving parts of the machine.

The following points should be observed in the location of the nozzles dependent entirely on the construction of the machine:

(1) Locate one nozzle directly above the cylinder if possible; if not, place it so that the beater will diffuse the spray from that nozzle.

(2) Run the pipe along underneath the roof of the machine with the nozzle pointing downward.

(3) Install a number of nozzles along this line, and so locate them that every chamber in the machine is thoroughly served by a nozzle.

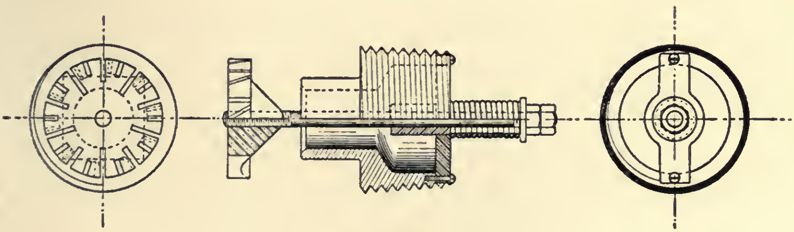
(4) Particular pains should be taken to serve dead air spaces, as it is in these that dust is likely to accumulate.

(5) As the stacker end of the machine is less likely to contain any closed chambers, it is probable that, in most types of machines, the nozzles at this end may be 30 inches or more apart.

(6) The last nozzle along the pipe line and within the machine should be just above the end of the shakers.

(7) One nozzle may be located in the wind stacker by means of a flexible connection from the pipe line.

The tripping mechanism of the automatic extinguisher is so arranged that it may also be released by hand, and also arranged so that it can be locked while on the road. Two pounds pull is sufficient to release it, but it has proved to be sufficiently rigid to withstand the jar and vibration due to threshing operations. In no case did it release itself prematurely. It would appear, that when not in use on the threshing machine, the ex-



SPRAY NOZZLE.

Fig. 36.

tinguisher can be mounted on running gears and used for general fire protection about the farm. A special spray nozzle designed for use with the extinguisher is shown in detail in Figure 36.

Water Under Pressure.

On a number of separators water tanks were used that could be pumped to 100 pounds pressure per square inch by a special air pump. These tanks were equipped with a system of piping from the tank to the separator much the same as used in chemical extinguishers. The results obtained did not appear to be entirely satisfactory, possibly because of the fact that as soon as some of the water had sprayed out the pressure dropped so rapidly that there was not sufficient pressure remaining to be effective. However, a number of machines were saved from total destruction by using this type of sprinkler. One installation consisted of a 40-gallon water tank on top of the separator connected to the engine pump which maintained a pressure of 70 pounds per square inch. By the pulling of a wire, the pipes from the tank were opened and the water carried to perforated pipes in the separator. No fires occurred in this machine so the tank did not receive a thorough trial.

Steam Line from Boiler to Separator.

In many cases steam or water hose was used from the engine boiler to the separator with satisfactory results. The popularity of such an arrangement was due to the comparative cheapness of the system (about $50 to $75) and also to the success attributed to it by the men who had used it. When regular steam hose was connected to a point on the boiler below the water line the best results were obtained. When the valve was opened at the boiler a volume of steam and water was obtained at pressure which was usually sufficient for extinguishing the fire. A steam pipe line was used when it was difficult to secure steam hose because ordinary rubber hose is not safe for a steam line. Steam piping made a much more clumsy installation but when swinging joints were properly installed it worked successfully.

Conclusions.

The methods of prevention developed by the U. S. Department of Agriculture have proved effective in reducing the losses from dust explosions and fires in grain threshing machines during their operation. Every machine operating in areas favorable to dust explosions, especially during the threshing of smutty wheat, should be equipped with a grounding system for removing static electricity, dust collecting fans and an effective fire extinguishing system. The results obtained by the adoption of these precautionary measures in the Pacific Northwest suggest the advisability of their extension to other grain growing sections where dust explosions and fires may occur during threshing operations.

CHAPTER IX.

PLANT CONSTRUCTION.

The construction of the plant can be a factor in the prevention of dust explosions and also in the extent of the explosion if it permits the presence of dangerous quantities of dust. Some of the most disastrous dust explosions in the United States and Canada have occurred in large terminal grain elevators and industrial plants built of fire resistive materials and well constructed as far as modern engineering principles are concerned. This fact indicates very definitely these plants must be well maintained and the explosion hazard recognized.

It has been demonstrated often and with costly results that so-called "fireproof" plants are not necessarily "dust explosion proof" and that the damage is usually very great when an explosion occurs in a plant of this type. This is not by any means intended as a reflection on construction of fire resistive materials, because in the opinion of the authors this is essential, but to develop and emphasize the point of proper upkeep and maintenance within the plant.

Advances in Construction.

Within recent years many changes have been made in the type of construction used for mills and elevators in this country. The old water-power mill constructed of logs and located along some stream from which it derived its power, is rapidly being replaced by larger mills of modern construction generally of reinforced concrete. Their location depends now more upon the source of grain supply and the market for their product because electric power has replaced the less dependable water power. Like the mill the small country elevator of frame construction is being replaced by more modern buildings of steel or reinforced concrete.

Within the mill and elevator numerous changes in the machinery and method of installation are found. Machines running at high speed have replaced the slow moving ones and the many improvements made have increased their capacity.

All of the changes mentioned above are closely related to the subject of dust explosions. In the old style frame building little if any attention was given to the collecting or removing of dust. Because of its construction the building was hard to clean, and it was difficult to protect it from explosions and fires. If a minor explosion occurred it was generally followed by a fire which completely destroyed the property. Realizing

this danger, the owner or manager took special pains to see that carelessness was not responsible for the starting of a fire in his plant. The workmen having a greater interest in the plant were probably more careful than the workmen of today. It has also been suggested that possibly the location of the plant along the stream with water often running directly beneath the building might also have helped in reducing the dust explosion hazard in these small mills as the inflammability of grain dust decreases as the moisture content increases.

The construction engineer's first step in the development of a better type of structure was to build of fire resistive material. The replacement of the old frame structures with those of brick, stone or reinforced concrete was a long step in the right direction, but it had this bad effect. It has caused overconfidence in the safety of the plant. The workman feeling that he is working in a "fireproof" plant has a tendency to carry open lights, strike matches or smoke in the building. Even the company officials have often been misled by the word "fireproof." In many instances the proper equipment for fire prevention has not been installed with the result that small fires have been permitted to assume large proportions and result in dust explosions. The most destructive explosion on record occurred in a plant where the company felt that insurance was not essential since there was no material in the construction that could burn.

Engineers now realize that it is useless to attempt to confine the explosion by types of strong construction. In fact light construction has proved effective in releasing explosion pressures and localizing the effect. The importance lies in recognizing that dust explosions build up excessive pressures and cause extensive damage when the construction does not permit the ready release of the pressure developed in the early stages of the explosion.

Since it has been found in dust explosion study that the larger the quantity of dust in a plant the heavier and more disastrous the explosion, more attention is being given to the installation of equipment and devices for the elimination of the dust. At the same time fire resistive construction is not only being retained but it is being improved. Modern types of dust collectors are being installed and special consideration is being given to the elimination of all possible lodging places for dust as it is realized that no collecting system gathers up all of the dust from beams, ledges, window sills, floors, etc. Where it is impossible to eliminate a ledge entirely it is the practice to bevel the exposed section to an angle greater than the angle of repose of the dust. In the modern mill or elevator the walls and ceiling are made as smooth and free from offsets as possible. Special precautions should be taken in the installation of the dust collecting system because there is always a certain amount of dust in suspension within the collector. For this reason provision should be made to have the collector exhaust outside so that if an explosion occurs within the collecting system the pressure can escape without doing any damage to the building. A better system perhaps is to have the collectors located outside of the buildings or in a detached section. One company has provided a dust house several hundred yards from the plant, large enough to accommodate a railroad car. The dust collecting system blows the dust

directly into the car from the plant and when the car is full it is removed and an empty one put in its place.

From general observation the most popular type of elevator construction used today and the one which appears to offer the greatest protection from damage by dust explosion is the cylindrical tank type built of steel or reinforced concrete. In some cases, generally in the smaller plants, square bins are used and prove very satisfactory. In both types the walls should be absolutely free from ledges inside or outside, and the bins should be covered. This arrangement is for the purpose of eliminating an air space or dust cloud over the bins and to prevent a fire in one communicating to the others. Manholes with ventilating covers should be provided at the top of each and a relief valve or opening from the top of a bin to the outside air is often advisable because it provides for the release of pressure should a puff or small explosion occur. All bins should be connected with a suction system which will remove the fine dust from the grain as it enters.

Special precautions should be taken in the construction of the work house because it is generally in this part of the plant that the fire or explosion originates. The building and equipment should be of fire resistive material throughout as far as possible. It is advisable to provide some means to relieve the pressure should an explosion occur. This can be accomplished in the modern daylight type of building by having large window areas of thin glass. Where there is considerable vibration and possibility of fire from without, wired glass windows loosely sealed to the frames should be used. Where the windows are opened frequently fine screens should cover the opening exposed to sparks from locomotives.

Steel curtain doors are being used in elevators on the working floor. During the day these doors are opened to provide good ventilation and to act as a vent to any explosion that may occur.

It is estimated that 80 per cent of the fires in mills and elevators start in the elevator head, legs or boots, a fact which shows that special attention should be given to this equipment. Non-chokeable elevators are now obtainable and they should be installed wherever practicable. A choked elevator will cause the belt to slip, stop or run out of line, resulting in friction fire and an explosion. Where electric power is used and an individual drive is arranged for each lofter this danger can be controlled by a cut-off on the motor which will shut off the power when the belt becomes overloaded. A full-bin alarm signal system is a handy device to have in the elevator as it will give a warning in time to prevent a choke if the grain backs up from the full bin into the elevator discharge spout. A weighted boot pulley can often be used to advantage on large elevators because it adjusts itself to the varying length of the belt when running light or loaded. Screens or a close grating should be provided to prevent any pieces of metal or stones entering the boot of the elevator with the grain. They are liable to lodge and cause sparks to be struck when the elevator buckets come in contact with them.

It is advisable to enclose elevator belts for their entire length instead of providing a well or vacant bin for them to run in between the bottom of the bins and the bin floor because this practice permits a large dust

cloud to collect at a point in the plant where it can do the most damage should an explosion occur. There should be provided separate legs for the up and down side of the belt and a relief valve and ventilator through the roof to the outside of the building for each large elevator lofter. All elevator heads should be connected with a suction system which will remove the fine dust.

In addition to that on the bins and elevator heads, suction systems should be installed to collect the dust at the cleaners, at the scale hoppers, at the tripper, and at the end of the belt conveyor where the light dust which sticks to the belt is thrown off as the belt goes over the pulley. Suction floor sweeps should be arranged to remove the dust which settles on the floor and at the bottom of the elevator pits. All garners, scale hoppers, and receiving bins if not equipped with a suction system should have natural vents run through the roof of the building to provide for the escape of the dust laden air from the bins when being filled with grain.

As a rule, elevator owners or managers as a result of regulations by the terminal grain exchanges do not look with favor on any system which they think will affect the weight of the grain they are handling and are of the opinion that suction systems will remove enough material to cause them a loss because of the reduction in weight of grain delivered from the weight received. Limited tests, preliminary in nature, show that this is not the case, and indicate that the collection of the light explosive dusts will not vitally affect the weight of the grain.

Electricity seems to be the favorite power in use today, and the tendency seems to be toward the individual drive. There are many advantages to this system since it is not necessary to shut down the entire plant because of a defect in one machine or motor. The squirrel cage type of induction motor is probably the most satisfactory because it operates on alternating current and the danger of sparking is reduced. Wherever possible the motor should be enclosed to prevent dust accumulating on the brushes.

In an elevator it is often the little things that count. One little spark may cause a disastrous explosion. The electric wiring should be in conduits or armored cable. The switch boxes should be well protected and kept closed when not in use. If possible they should not be placed in a dusty section of the plant. The light globes should be well guarded. Vaporproof globes are proving very satisfactory in plants of this kind, and they should be installed wherever there is danger from dust. Static electricity in a dusty mill or elevator is dangerous because it collects on belts and machinery and produces sparks when it jumps from one body to another. This hazard can be eliminated by grounding all belts and machines on which static electricity is found. A wire running from the machine or belt to the ground prevents the building up of a charge and the formation of the spark.

In the year ending April 30, 1919, of 78 elevator fires in which the cause was reported, 19 were caused by lightning. It is well therefore to protect the property with lightning rods that are well grounded. Fifteen of the fires mentioned above were caused by locomotive sparks. As suggested previously, all windows or openings on the side of the plant facing

the railroad where sparks might enter the building should be carefully screened.

In addition to taking all precautions to prevent fires the property should be well supplied with fire-fighting equipment in case the unexpected happens. A sprinkler system is probably the best protection that can be obtained. A sprinkler head should be installed in the head of each elevator leg. Care should be taken to avoid placing the main supply pipes of the system in a position where they might be ruptured in case of an explosion. This has happened in a number of cases and the plant has been left entirely unprotected as a result of the destruction of the sprinkler system by the initial explosion. The small extinguisher and the stand pipe and hose are also valuable in fighting fires which might otherwise gain headway and spread to a dusty portion of the plant and cause an explosion. Such apparatus should be provided wherever necessary.

The same type of fire-resistive construction suggested for elevators is adaptable to other types of industrial plants and to flour and feed mills. There should be plenty of light and good ventilation. Especially in flour mills, attention should be given to general appearance and cleanliness. A food product is prepared in these plants, and cleanliness is of the first importance. There should be no lodging places for dirt or vermin. It is well to have the milling and grain cleaning departments separate to prevent the dust caused by cleaning the grain spreading through the mill. Any feed grinding done in connection with the milling business should be done in a separate building or a detached section of the main plant.

The records show more explosions in feed than in flour mills, and this has been credited to the cleaner condition in which the flour mills are generally kept. It is a good plan to place the cloth dust collectors which are commonly used in flour mills, on the top floor or in a detached section of the plant. Should an explosion occur and follow the air current through the trunking to these collectors its effect will be confined to that section of the plant in which the collectors are located.

In milling plants as well as in elevators, the construction engineer has taken steps to eliminate the large dust cloud. In a mill the dust cannot be destroyed or blown outside the building because it is a part of the product, but arrangements can be made to prevent large accumulations of it in one place. Small tanks for temporary storage of the ground product before sending it to the large storage tanks are advisable. They should be large enough to hold a half day's run of material, and enough of these should be provided to allow the product to remain in them 24 hours. If any hot metal or smoldering embers have entered these tanks with the feed and started it burning, the fire will be discovered before the material is sent to the large tank, and the loss will be confined to the amount of material in the temporary storage tank.

Small bins kept well filled are much safer than large ones only partly filled and having a quantity of dust in suspension. This is especially true of storage bins inside the plant. One company has eliminated even the reserve bin over the packer. The material is packed direct as it comes from the conveyor leading from the grinding machine to the packer.

The same general suggestions made for elevator construction apply also to mill construction. The general rules now widely observed in new construction are:

1. Build of fire resistive material.
2. Use fire resistive equipment.
3. Eliminate all ledges or lodging places for dust, or bevel all ledges that cannot be eliminated.
4. Eliminate all large storage bins inside the mill building or work-house.
5. Convey direct to packer wherever possible.
6. Provide plenty of light and good ventilation.
7. Use wired glass windows and protect all openings with screens on sides of property adjoining railroad or other buildings.
8. Install dust collecting systems.
9. Install suction at all points where dust is produced.
10. Place dust collectors outside the building or in a detached section.
11. Protect the plant with approved lightning rods.
12. Ground all machines or belts where static electricity might be formed.
13. Install sprinkler system or other efficient fire-fighting equipment.
14. Keep buildings a safe distance from each other to prevent damage of all by an explosion or fire in one.

CHAPTER X.

COTTON GIN FIRES.

For many years the cotton gins of the South have experienced more or less trouble with fires. Some sections of the country seemed to be affected worse than others. In the fall of 1917 the gins in the western cotton belt, especially in Texas and Oklahoma, were troubled with an unusually large number of these fires, and many plants and large quantities of cotton were destroyed. From such information as could be obtained it appeared that the weather conditions at the time of this epidemic of fires were similar to those which prevailed in the Palouse country of the Pacific Northwest when large numbers of dust explosions occurred in grain separators. As stated in Chapter VII these explosions were found to have been caused largely by the ignition of dust by the discharge spark of static electricity. It was thought that this same condition might have existed in the cotton gins, that is, that the cotton was ignited by static electricity. Owing to the lateness of the season when the news of the epidemic reached the authors, it was possible to make but a brief preliminary investigation.

The available information showed that the fires began late in September and that they were unusually frequent until rains set in about the twentieth of November. During this period of about two months the rainfall was negligible and the humidity was very low, a condition very favorable for the generation and accumulation of static electricity.

During the fall of 1918 investigations were carried on throughout the cotton belt of Texas and Oklahoma to determine, if possible, the cause of these fires and to develop means of prevention. As far as possible, the scenes of the fires were visited and thorough first-hand investigations were made. In some cases letters were sent to the owners of the property and the information was obtained by mail. In connection with these investigations and through contact with insurance companies and with ginners who had not experienced fires in 1918, considerable information was also obtained on the general subject of fires in cotton gins and more especially on the conditions surrounding the fires of 1917.

It seems that there is hardly a step in the ginning process where fires do not occur at one time or another. They have been known to start in the farmers' wagons and to be drawn up into the gin machinery, and also to break out in the baled cotton after it had been removed from the gin to the storage yard. Ginners do not altogether agree as to the point

in the gins where most of the fires originate. They are prejudiced, naturally, by their own experiences. For instance, some gins have had fires only in the cleaners or between the wagon and the huller breast of the gin; some have experienced fires only in the huller breast or in the gin proper; while others have had no fires except in the bales after they have been tied out.

Many different opinions as to the causes of these fires have been advanced, but the cause which ginners consider responsible for most of the

Cotton gin at Elm Mott, Tex., destroyed by fire August, 1918.

fires is matches in the seed cotton as it is brought to the gin. In fact, out of 394 fires which were investigated during the season of 1918, and to which definite causes were assigned, the origin of 205 was attributed by the ginners to matches. The next highest number from any one definite cause was that assigned to the hanging of cotton in the ribs of the gin. The sticking of the cotton in the ribs is supposed to be a result of the ginning of damp or wet cotton, of rough places on the ribs, or of dull saws. Foreign material in the cotton, friction in the machinery through its misalignment, and hot bearings are other causes. A few ginners expressed the belief that static electricity was responsible for most of the trouble. In most cases these men had formed their opinions from their particular experience with the static in the gins and the means employed for removing it.

In order to determine the actual danger from matches in seed cotton, arrangements were made to conduct a series of tests in two different types of gins. In one case more than 500 of the ordinary birdseye matches, which can be struck easily, were placed in about half a load of cotton. This was then drawn through the gin in the regular process. No fires broke

out in the cleaner, in the pneumatic distributor, the feeders, the stands, the lint flue or the bales. Two small fires, however, occurred in the huller breast, but they were easily extinguished. In another case 38 marked matches were placed in about 600 pounds of seed cotton in the seed-cotton house, whence they were drawn along with the cotton into the cleaner. The feeders were shut off, thus forcing the cotton out through the overflow. No fires occurred. Then 47 more matches were added to the cotton on the overflow and the whole was again drawn through the cleaner and allowed to go on through the feeders to the gin in the usual way. Again no fires were observed in the cleaner, the belt distributor, the feeders, the gin stands, the lint flue or the bale. As in the previous test, however, two small fires occurred in the huller breast, and were as readily put out. These results, only four small fires in the huller breast from nearly 600 matches in less than one load of cotton, would seem to indicate that matches were not as important a factor in the starting of fires as had been supposed, and especially at any other point than in the huller breast. It was, therefore, necessary to look for some other cause.

During the period of the investigation, all possible information was obtained as to the date of the fires, the time of day they occurred and all conditions peculiar to each fire. Records were also obtained from the Weather Bureau showing the relative humidity on the different days in various sections of the affected territory. A comparison of all the fires, the dates of which are definitely known, with the average relative humidity in the sections in which the fires occurred is shown in curves in Figure 37. The dotted line in the upper curve indicates the total number of fires which occurred on any one day, while the solid line indicates the number of fires which occurred in the cotton cleaners. Below these, a solid line curve shows the average humidity in the inverse ratio, that is, the curve rises as the humidity decreases. It will be noted in these curves that the largest number of fires have occurred during periods of low humidity, and that there is a similarity in the direction of these curves. If the dates of all fires were included, there is no doubt but that this relation would be much more noticeable, because in the case of 213 fires, the exact date of which could not be obtained, it was found that 19 occurred about the middle of August, 35 in the middle of September, while 13 took place in the first week in October. These data would indicate that some relation must exist between the atmospheric conditions and the fires, especially those starting in the cleaners.

In Table XXIII it will be noticed that the largest number of fires occurred between 2 and 5 in the afternoon, that part of the day when the temperature is normally the highest and the relative humidity is lowest.

It was not determined whether the changing of the relative humidity from morning to afternoon would have an appreciable effect on the moisture in the cotton, but it is doubtful if it would have on account of the shortness of the time, but a few days of low humidity would certainly decrease the moisture content of the cotton, and thereby increase the ease with which it might be ignited. There was also a marked difference in the amount of static electricity present in various parts of the gin at

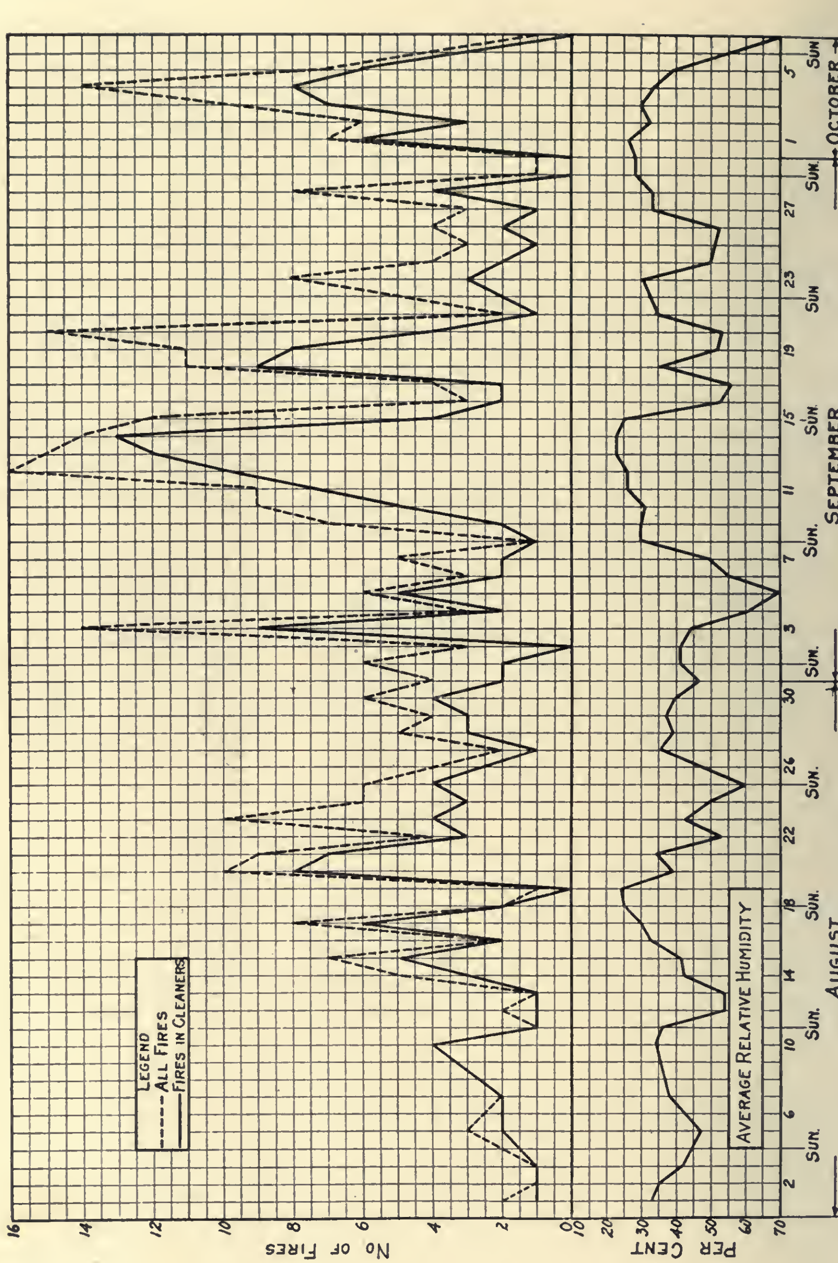


Fig. 37.—Cotton Gin Fires and Relative Humidity, August to October, 1918.

different times of day. It was much more noticeable in the afternoon than at any other time ordinarily, but during periods of low humidity there was little or no change during the day.

The fall of 1917 was one of the longest periods of drought and of low humidity experienced in the western cotton belt during the ginning season. From the information obtainable it was found that the fires occurred almost entirely during this dry weather and that very few started after the rains began. During this time static electricity was present in such large quantities in some gins that it was not possible to

TABLE XXIII.

TIME AND LOCATION OF FIRES IN COTTON GINS.

Time of day.	Cleaner.	Huller.	Stands.	Bale.	Total
2 a. m.			1		1
7–8 a. m.	1				1
8–9 a. m.	2	1	1		4
9–10 a. m.	7	1	1		9
10–11 a. m.	13	5	5	1	24
11–12 a. m.	15	6	3		24
12–1 p. m.	13	4			17
1–2 p. m.	10	3	5	2	20
2–3 p. m.	42	5	3	2	52
3–4 p. m.	48	11	2	4	65
4–5 p. m.	27	3	4	2	36
5–6 p. m.	10	4	1		15
7–8 p. m.			1		1
8–9 p m.	3		1	1	5
9–10 p. m.	5	1	1	2	9
10–11:30 p. m.	2				2
Morning	4	2		1	7
Afternoon	21	9	2	2	34
Not given	13	5	7	10	35
Total	236	60	38	27	361

operate them, and steps had to be taken to remove or dissipate the charge. It was not only noticeable on the machinery, but it was present in such quantities that it was almost impossible to handle or approach any part of the machinery. It would also cause the cotton to stick in the lint flue and in other parts of the gins, gradually clogging them up until they would not operate, holding the cotton as a magnet holds pieces of steel. At such times it was often necessary to close down the gin and to clean out the cotton before operation could be continued. In many cases sparks 4 to 6 inches in length could be drawn from various parts of the machinery. During this entire period fires were occurring so frequently that it was not unusual to have 6 or more fires in a gin during a single day.

In order to overcome their trouble with the static electricity, the ginners resorted to various methods. In one instance live steam was injected into the suction pipe before the cotton reached the cleaners. Often the

entire gin house was wet down frequently during the day. In other cases wet burlap was kept suspended in the plant. In some gins where there was particular trouble in the lint flues, bagging or wet blankets were used to humidify the atmosphere to remove the static charge. It is interesting to note that practically no more fires occurred in the gins which employed any of these measures to remove static electricity.

As it was argued by many that a static discharge did not have sufficient igniting power to fire cotton, tests to determine the accuracy of this

Result of cotton gin fire at Denton, Tex., August, 1918.

statement were made in the Southern Methodist University at Dallas, Texas, where a static electrical machine was available. No difficulty was experienced in igniting the cotton even with a very short spark. Reference has already been made in the chapter on Static Electricity to the work conducted in co-operation with the Bureau of Standards. After these practical demonstrations there would seem to remain no chance to doubt that static electricity will ignite cotton, and that it is one of the most common causes of fires in cotton gins.

During the investigations, information was obtained on 695 fires which occurred during the 1918 season. Inasmuch as 404 of these occurred in the cleaners or at some point between the wagon and the feeder, full particulars were obtained, so far as possible, as to the type of cleaners used in these various gins. The relation between these different cleaners in use in the gins visited and the number of fires which have occurred in them is shown in Table XXIV.

It will be noticed that these have been arranged according to the number of cleaners in the gins visited, the largest being given first. It is interesting to note that fires were experienced in fully 50 per cent of cleaners of three different types which were in use, Nos. 2, 4 and 7; in 26.4 per cent of cleaners of the type most largely in use; and in only 14 per cent of another type. It is believed that this difference is caused almost entirely by the construction of these cleaners, as those in which most of the fires occurred seem to be of a type in which static electricity

TABLE XXIV.

FIRES IN GINS WITH VARIOUS TYPES OF CLEANERS.

Type of cleaners.	Total No. cleaners.	Cleanors having fires.	Fires in other portions of gins.	Gins without fires.	Total per cent having fires.
No. 1	292	77	85	130	26.4
No. 2	139	70	15	54	50.4
No. 3	50	7	16	27	14.0
No. 4	48	24	10	14	50.0
No. 5	42	13	9	20	31.0
No. 6	36	11	10	15	30.5
No. 7	27	13	4	10	48.2
No. 8	12	2	2	8	16.7
No. 9	8	3	3	2	37.5
Miscellaneous	4	3	1	—	75.0
No type given	86	10	10	66	—
No cleaners	—	—	—	15	—

may be most easily generated and may accumulate in largest quantity, as well as being so constructed that this discharge, as for instance between the screen and the cylinder teeth, may most easily occur. Although not as many fires were reported during 1918 as during 1917, steps were taken to equip about 40 gins in different sections of the cotton belt in such a way that the static electricity would be carried away as fast as it was generated. While these gins were of various makes, the same general principle was applied in each case, that of grounding every moving part of the gin and every metal part over which cotton was moving.

An outline of the method of wiring is shown in Figure 38. All metal parts are connected by No. 14 insulated copper wire. At least three heavy insulated wires (No. 10) are run to the underground water pipes, or to rods driven 4 or 5 feet or more into the ground. Starting from the suction pipe, contacts are made to the telescope pipe, or the flange, just below the canvas joint, with one or two more contacts between it and the cleaner, depending on the length of the pipe. This wire is run on into the cleaner, making contacts to all the screens—two on the larger ones—as well as to all journal boxes on at least one side of the cleaner. The wires from these contact points are brought together. A wire is run from this point to all journal boxes on one side of each feeder and

gin stand, to all the screens of the cleaner feeders, and to the lint flue bringing wires from these points together. Contacts are also made to the overflow telescope, and suction pipe. These wires are then connected

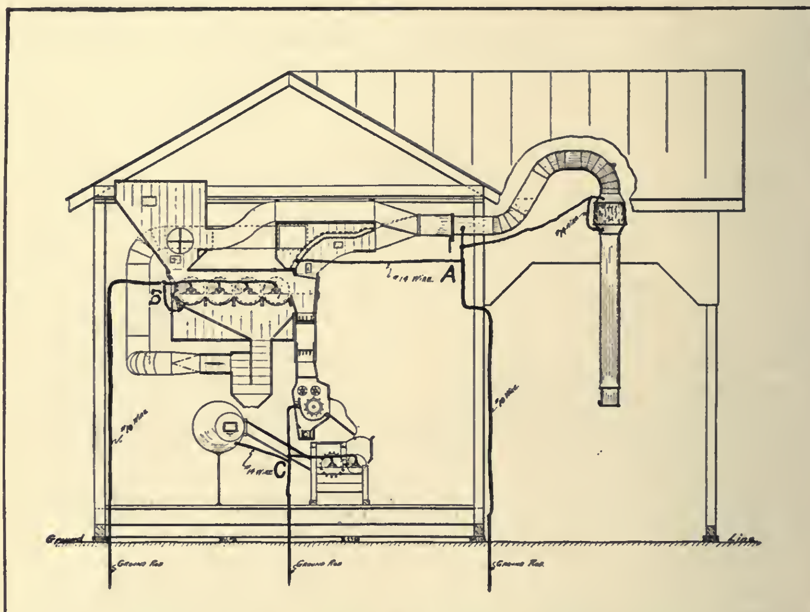


Fig. 38.
Method of Wiring Cotton Gins to Eliminate Static Electricity.

with the ground wires at the following points: (A) Where the wires from the suction pipe meet; (B) where the cleaner connections come together; and (C) where the connections from the stands, feeders, and lint flue are brought together.

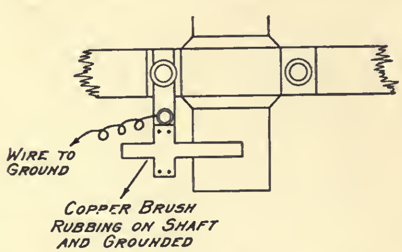


Fig. 39.
Brush Contact for Revolving Shaft.

The insulation should be removed from the wire and the wire scraped bright at the point of contact, taking care that all dirt, oil, and rust are removed. The contacts must be made as tight as possible. Wherever possible, brush contacts (Figure 39) should be used on revolving shafts rather than simply making a connection to the journal box. All connections in the grounding rods should be securely soldered. Following the grounding of the gins, no more fires of apparently unknown origin occurred except in one of these gins. Here three fires occurred, two of

which were caused by the hanging of cotton in the ribs. The other started in the cleaner. The cause was not known but it was supposed by the ginner that a stone got into the cleaner and created sparks when it was struck by the cylinder teeth.

There is no doubt but that many fires are started from other causes than static electricity. Doubtless matches and foreign material in the cotton have started many fires. Perhaps the chief cause of fires in the lint flue and those which break out in the bale after it has been tied out is the hanging of cotton in the ribs, causing friction which eventually ignites the cotton. It is quite probable that the static electrical charge pulls and holds the cotton and is responsible for some of this hanging of the cotton in the ribs. Friction in the gin stands from other sources may also result in fires. Sometimes a spark or smoldering piece of cotton will be carried on from the stands through the lint flue and no fire will be noticed until it reaches the condenser. It is quite probable that many of the fires which occur during the night, after the gins have been closed down, are caused by sparks getting into the piles of cotton lint, which are often found in the bottom of the condensers. As in the case of fires in the bales, they may not break out into actual flame until some time later, when they have eaten their way out to the surface.

In order that fires in cotton gins may be prevented the following precautions should be taken:

1. Thoroughly ground all metal and moving parts of the gin, thus eliminating the static electricity.

2. Educate the neighboring farmers and cotton pickers to keep the cotton as free as possible from matches and other foreign material.

3. Clean the plant thoroughly at least three times a week, thus freeing the premises from the lint through which fire spreads rapidly.

4. Refuse to gin wet or even damp cotton, as this tends to hang in the ribs and produce friction.

5. Keep the saws sharp and the huller ribs and the gin ribs as clean as possible.

6. Clean out the condenser every night and immediately after every fire.

7. Inspect all parts of the plant after closing, lest some hot box or smoldering cotton give rise to a fire.

8. Use automatic oilers on all bearings, thus preventing hot boxes and the dripping of oil from the boxes on accumulated lint or seed cotton, with the resultant spontaneous combustion, and at the same time effecting an economy in the amount of oil used.

9.. Store no baled cotton on the platform or less than 100 feet from any building.

10. Prohibit smoking and carrying matches in or around the plant.

11. Keep ample and efficient fire-fighting apparatus easily available at all times.

12. Keep all machinery in proper alignment.

That static electricity plays an important part in cotton gin fires, and that grounding of the gins so as to remove it will prevent a large number of fires are attested by the fact that some of the insurance companies carrying cotton gin insurance have already made a reduction in their rate of 25 cents per $100 of insurance for the gins which are properly grounded.

CHAPTER XI.

COAL DUST EXPLOSIONS.

Origin of Coal Dust Investigations.

The first important investigational work in the United States on the dust explosion problem was undertaken by the Bureau of Mines in connection with coal dust. It appears that interest in coal dust explosions was not generally created among mining men until a series of disasters in 1907. During that year 1148 men were killed by mine explosions in the United States, 648 of that number losing their lives during the month of December as the result of coal dust explosions. In one mine in West Virginia 358 men were killed, while in another mine in Pennsylvania 230 men lost their lives. This series of disastrous mine explosions aroused considerable interest among mining men, and an appropriation was made available July 1, 1908, for the investigation of the causes of mine explosions and development of methods of prevention. This action by the Federal Government resulted in the creation of the Bureau of Mines in the Department of the Interior, and the beginning of progressive research investigations pertaining to the explosibility of various types of coal dusts.

The investigations by the Bureau of Mines at times extended to dust explosions in representative industrial plants, in order to obtain all possible information on the nature and action of these occurrences. In certain instances investigations of explosions in grain mills were undertaken to secure data which the engineers of the Bureau felt would be helpful in the study of coal dust explosions. In the progress of these investigations, a destructive explosion in a feed grinding plant in Buffalo on June 24, 1913, was thoroughly studied. The explosion resulted in the loss of 33 lives, injuries to 80 others and extensive property damage. The interest manifested by the milling and grain companies of Western New York and their desire to adopt all possible means of prevention, resulted in a co-operative investigation with the Bureau of Mines to extend the study to cereal dusts. The work was financed by the Millers Association and directed from the Pittsburgh Laboratories by Dr. George A. Hulett, then Chief Chemist of the Bureau of Mines.

These investigations initiated by the Bureau of Mines indicated the importance of the study to the grain industries of the country and resulted in definite arrangements being made for its continuation in the Bureau of Chemistry of the Department of Agriculture. It is significant

to note that although primarily created for the investigation and control of coal dust explosions, the Bureau of Mines was the agency through which the importance of industrial plant dust explosion prevention was brought to the attention of the country. The equipment and facilities available in the Bureau, combined with the valued experience of well

Barrier of 6 boxes in mine entry. Rock dust is protected by oilcloth covers. The wiring at the upper right hand corner is not a part of the barrier.

trained engineers, made it possible to determine the explosion hazard in industrial plants and factories and to outline definite lines along which the development of methods of prevention could be undertaken.

Early Investigation.

The early investigations on coal dust explosions were in charge of Dr. Joseph A. Holmes, at the time expert in charge of the technologic branch of the Geological Survey and later appointed as first Director of the Bureau of Mines. Dr. Holmes called to his assistance George S. Rice, a prominent mining engineer who had devoted considerable time to the study of explosions and had given the problem a great deal of attention. One of the first undertakings in 1908 was a survey of the experimental coal dust explosion galleries in European countries, which included the earlier testing stations in Belgium and Germany, and the newly installed stations at Altoffs, England, and Lievin, France. The investigations

abroad resulted in the installation of a dust testing gallery at Pittsburgh, Pennsylvania, and the subsequent development of an experimental coal mine for large scale tests.

Experimental Mine.

The engineers entrusted with the experimental work in the Bureau of Mines decided that results of the greatest practical value could be obtained by the opening of a new coal mine rather than by the use of an abandoned mine as was first projected. This brought into being the Experimental Mine located at Bruceton, Pennsylvania, about sixteen miles from Pittsburgh, Pennsylvania. The results of the tests at this mine have been a valuable contribution to the knowledge available for the prevention of coal dust explosions, and have made possible determinations for direct application in the control of dust explosions in industrial plants.

It was very essential that actual mining conditions be reproduced in this experimental work, and this indicated the necessity for a practical coal mine in preference to surface galleries as had been in previous use in the European testing stations already referred to. The large scale explosion tests in the mine were carried out simultaneously with the laboratory work. It was found early in the investigations that the laboratory or surface gallery work did not always duplicate or agree with the results obtained in the large scale mine tests. It was found that mixtures of dust and air which would not explode in laboratory apparatus or the surface gallery could be ignited with explosive violence in the mine. It was found that by using the empiric method of introducing oxygen into the explosion laboratory flask as referred to on page 21, Chapter I, in place of air in order to obtain more complete combustion, results parallel to those of the experimental mine were obtained.

Important Contributions of Bureau of Mines.

Much valuable work has been done by the Bureau of Mines in the study of the causes of explosions of coal dust and of fires and in developing methods for their control and prevention. It is not the purpose of this chapter to go into detail or attempt in any manner to cover the coal dust explosion problem completely. It is only desired to refer to the progress made by the Bureau of Mines in handling this very important problem and to the close relation to the other phases of dust explosion prevention. The publications of that Bureau are available and will be of interest to anyone desiring to obtain additional knowledge on the subject.

The following lines of work may be included among the most important contributions of the Bureau of Mines in the study of coal dust explosions:

(1) Determination of the explosibility of different dusts based on size and kind of dust, such as the volatile total combustible ratio and moisture.

(2) Determining the explosion hazards of different coal mines by duplicating the condition of the dust found in the particular mine. In

these tests it has been found that fine grinding entirely alters the limit of explosibility of naturally coarse and moist dust. For example, the sub-bituminous coal or lignite dust when finely ground is one of the most explosive of dusts. On the other hand, however, dust explosions are practically unknown in American sub-bituminous or lignite mines. The reason advanced is that when coal dust is freshly made at the working

Box barrier Model C after dumping.

face in the mine it is in rather coarse particles and retains natural moisture which dries out in grinding.

(3) The employment of mechanically operated inert dust barriers for the prevention of flame propagation. While the engineers in the Bureau believe that the best explosion protection is a thorough rock dusting throughout the mine, the Experimental Mine tests have shown the employment of closed barriers[1] to be very effective, as an additional check, in mines especially where watering the dust is practiced. The closed mechanically operated barrier which has proved very effective was developed when it was found that the Taffanel (French) shelf barrier

[1] The development of these barriers and also the development of curves of explosive limits of various coal dusts ranging from semi-anthracite to lignite has been largely the personal contribution of George S. Rice, Chief Mining Engineer. He has assigned the patent rights of all barriers designed by him to the Bureau of Mines, so that the mining industry may make free use of these patents.

did not operate in slow explosions and in mines with high humidity where the dust would become damp or wet. In the tight containers, or closed barriers, the dust is kept dry, and they operate at a given velocity of air which is a little in excess of a shock wave from an ordinary shot. These barriers have also been found to operate with the slowest explosions tested by the Bureau of Mines.

(4) The finding, or determination of, and registration of "retonation" waves, or those that return toward the origin of the explosion. Some remarkably interesting behaviors of these explosion waves have been recorded by the Bureau.

(5) It has been determined definitely that high humidity, or even saturated air, was not an obstacle and did not prevent flame propagation. It was necessary for the dust to be so wet that it was impossible to raise it by concussion. In connection with this investigation, the French apparatus designed for measuring velocity of the flame and the pressures of an explosion was more highly developed by providing for the simultaneous registering of the flame velocity upon the pressure record. A movement-of-air recorder and an entirely new device for gas sampling, which opened at a predetermined time and closed at a predetermined interval, were also developed.

(6) The work at the Experimental Mine has been of such a nature that from the analysis the engineers can practically determine in advance the explosibility limits of the dust. This has made possible the arrangement of a system of curves showing the range of explosibility of various coal dusts.

Causes and Methods of Prevention of Coal Dust Explosions.

The investigations of the Bureau of Mines have demonstrated that widespread explosions in coal mines are preventable if methods that have been tested in an experimental way and in practice are used and if care is exercised at all times by every one in the mine. It has been found that bituminous and lignite dusts were the causes of disastrous mine explosions in the United States while on the other hand it is significant to note that anthracite coal dust is not explosive and that explosions in anthracite mines (due to methane gas) have always been very local in character. This is of particular interest since the methods of preventing fire damp (methane) explosions are usually discussed as entirely apart from the methods of preventing coal dust explosions, although in many of the most important coal mining districts of the United States the sources of danger are much the same.

Matches, open lights, long flames and long duration of flame from black powder, dynamite, or other non-permissible explosives; electric arcs from grounding of trolley or power wires, and flames from mine fires can be classed as ignition sources. It is not possible for an explosion of coal dust or any other explosive dust to take place without the presence of open flame of some kind. The long flame from "blown out" black powder shots and also the ignition of pockets of gas by open lights are common causes of ignition of coal dust. It is not essential to have in-

flammable gas present to cause an explosion of coal dust as was originally supposed, but tests at the experimental mine have shown that inflammable gas increases the sensitiveness of the dust to ignition. It has been found that with each per cent of methane gas present in the mine air it requires an additional four to five per cent increase in inert matter—ash and moisture—in the coal dust.

Permissible explosives approved after tests by the Bureau of Mines, on account of their small flame and its brief duration, when properly used will not ignite dust. The Bureau engineers feel that if these per-

Effect of violent explosion on box barrier.

missible explosives were employed throughout the coal mines of this country to the exclusion of black powder, dynamite and other explosives of a character dangerous to use in coal mining, nearly one-half of the coal mine explosions would be prevented. If safety lamps or permissible electric lamps approved in Bureau tests, were used, even in the so-called gaseous mines, it is thought that over one-third of all the mine explosions in this country could be prevented.

Making Coal Dust Inert.

In considering the control of dust explosions in industrial mills and elevators, it is interesting to note that the experiments by the Bureau of Mines show that after a thorough "dry cleaning" and sweeping in a mine,

there would still be enough coal dust in the average mine to propagate an explosion once started. This was shown very strikingly in a series of tests at the experimental mine during the winter months when the mine was dry.

In describing these tests the Bureau states that the mine was thoroughly cleaned with shovels, brushes and jets of compressed air, assisted by a strong air current moving in the direction of the cleaning. The explosion was started by means of a "coal dust zone" a few hundred feet long, and in several tests the explosion swept violently through the supposed "dustless zone" previously cleaned—1000 feet in length. It was definitely demonstrated that it is necessary to do something more in a dry area than to brush or shovel up the dust. The only two effective methods protecting the mine from dust explosions are (1) wetting the coal dust and (2) covering it with rock dust or other inert material.

For finely divided coal dust to be non-explosive, it must contain at least 30 per cent (of the weight of the dust) of mechanically-held moisture. The following methods for wetting the dust have been followed with varying degrees of success: (1) Tank car or water wagon; (2) water hose; (3) calcium chloride or other deliquescent salts; (4) water sprinklers; (5) steam jets for humidification.

Inert Dust to Render Coal Dust Non-Explosive.

The Bureau of Mines has conducted extensive investigations pertaining to rendering coal dust non-explosive by means of "inert dusts." The theory of application is as follows: The inert dust is forced into suspension in the air by the same concussion that raises the dry coal dust when the explosion originates—the inert dust absorbs the heat of the flame present and restricts the transfer of heat and flame by separating the individual particles of coal dust by its own inert particles. In this manner flame propagation is prevented and the extent of the explosion localized. In the tests it was found that with a mixture of from 60 to 70 per cent shale dust, or 60 per cent limestone dust, an explosion of Pittsburgh coal dust could be prevented. The results of these tests suggest a possible application of the use of inert dusts in industrial plant explosion control.

Rock Dust Barriers.

Considerable work has been carried on at the experimental mine to determine the efficiency of various types of so-called "rock dust barriers" as a supplementary means of stopping explosions that have started in spite of precautionary measures. These barriers are not intended in any way to take the place of any of the other preventive means and must be regarded only as secondary safeguards.

The investigations of J. Taffanel, director of the French mine-testing station at Lievin, suggested the use of rock dust barriers as a means of controlling coal dust explosions. He was able to block or extinguish an explosion by blockading the testing gallery with a pile of earth filling over

one-half of the cross section of the gallery. This led to the development of a group of shelves across and over the roadway laden with shale dust or ashes and termed "Taffanel barriers."

In the work at the experimental mine the Bureau of Mines used the Taffanel shelves in an effort to localize certain experimental explosions. It was found that they were almost uniformly successful with the moderate and violent explosions, but that the flame of a light explosion or

Side view of Type A concentrated barrier after dumping.

what might be termed an inflammation, would sometimes pass. This resulted in an effort by the engineers of the Bureau to design other devices that would be more sensitive.

Types of Barriers Developed.

A number of types of barriers have been designed and tested with favorable results. The designer, George S. Rice, has assigned the patent rights to the Bureau so that the mining industry can make free use of these patents. The following types of barriers have been designed:

1. Box barrier (consisting of 6 to 8 individual boxes).
2. Concentrated barrier.
3. Rock-dust ventilating stopping.
4. Rock-dust-protected ventilating door.
5. Rock-dust-protected overcast.
6. Trough rock-dust barrier.

Principle of Operation.

The barriers operate on the principle of throwing a mass (2 to 5 tons) of rock dust or other finely ground non-flammable dust into the "pioneer wave" that always precedes a dust explosion. This air wave

mixes the inert dust with the explosive coal dust so that when the flame of the explosion reaches the mixture, the inert dust absorbs the heat and extinguishes the flame. On account of the large quantity of inert dust used, each small particle of coal dust is surrounded by many particles of inert dust, which gives a cooling effect similar to the principle of the original Davy safety lamp. This results in extinguishing the flame from the explosion and thereby confining the explosion to a limited area and preventing propagation throughout the entire mine.

The dusts that have been tried with success in these barriers are shale dust and limestone dust, but the engineers of the Bureau of Mines feel that there are doubtless many other kinds of fine inert or incombustible dusts which would be effective. The dust is most effective when it is finely ground and free from combustible matter.

Description of Barriers.

It is not the intention to describe fully the various rock dust devices[1] that have been tested and have given successful results. It is desired, however, to refer in a brief way to two of these devices, namely, (a) the box barrier and (b) the concentrated barrier as described by the Bureau:

The Box Barrier—Construction.

"The box barrier, as is indicated by the name given it, consists of six or more boxes containing incombustible dust, open topped except for a loose waterproof cover, hung loosely from roof supports 2 to 3 yards apart and extending across the entry near the roof in such a manner that the explosion wave will cause them to be upset, thus throwing into the entry a large amount of incombustible dust. The bottom boards of the box are so arranged that after a short fall they are caught by chains attached to the roof, some of the dust being retained on these boards. Two grids within the box, which rest loosely on blocks and are connected to the same chains at distances of 3 and 6 inches below the top of the box, also retain some of the dust and allow the balance to fall through the open spaces. The boxes are hung high enough to be clear of traffic, a requirement that in a thin coal bed may necessitate the roof being 'brushed' or ripped down for a distance of 50 or 60 feet."

It was found in the tests that if the explosion reached the boxes, they operated successfully and, with rare exceptions even in the earlier types, extinguished the flame of the explosion.

The Concentrated Barrier.

The concentrated barrier, as its name implies, consists principally of two large but shallow containers of incombustible dust placed overhead across the entry way and supported near the roof by hinges and catches. The latter in turn are held by a leverage system so adjusted that the system is released when the pressure of an advancing air wave, operating against

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[1] This data can be obtained from the Bureau of Mines and also by reference to Technical Paper No 84, dealing with preventing and limiting of explosions.

swinging vanes, reaches a predetermined amount. The vanes are hinged planks 100 feet or more from the barrier on either side, the pressure being converted into a pull by a chain passing around a pulley and transmitted by a strong wire from the chain to the releasing mechanism.

When the catches are released the hinged containers swing quickly downward under the heavy load of rock dust.

The box barrier and the concentrated barrier were found to be particularly sensitive. By means of additional tripping vanes, 100 feet or

Effect of light explosion on Type B concentrated barrier.

so in advance, the concentrated barrier may be operated by the slowest moving explosion. The Bureau reports that velocities of flame as low as 100 feet per second have been recorded as compared with twenty times this speed in a fast violent explosion.

Explosions in Coal Handling Plants.

Attention has been directed to the possibility of dust explosions in connection with coal handling or storage in industrial plants. The same precautionary measures should be adopted that are now generally being followed in industries where explosive dusts are created during the operating processes. Efficient dust collecting systems should be installed for dust removal and the plant should be kept in clean condition. The ig-

nition sources already referred to as possible causes of coal dust explosions should be eliminated as much as possible and attention given to proper maintenance and upkeep. The results of the investigations of the Bureau of Mines in connection with the causes of coal dust explosions and the work of the Bureau of Chemistry pertaining to industrial plant dust explosions should be applied in a practical manner.

Value of Bureau of Mines Work.

Much of the material in this chapter has been taken from reports and publications of the Bureau of Mines which were made available to the authors. It has been necessary in many instances to give almost verbatim the results of the tests and especially the work at the Experimental Mine. This has been done with the realization of the practical application of this valuable work to the prevention of explosions in industrial plants and manufacturing establishments, and with the expectation that it will be of economic value in reducing the losses to life, foodstuffs and property.

CHAPTER XII.

REVIEW OF EXPLOSIONS.

It may be inferred that dust explosions have occurred ever since any inflammable dust was manufactured or created in an industrial plant. However, in the early history of industry, the plants were of such size and construction that an explosion was nothing more than a very rapid propagation of flame. There was no report or particular explosive force as the machinery was not enclosed and the buildings were of such construction that sufficient pressure was not built up. In many small industrial plants explosions of such a nature have occurred that, if they had started in a larger plant or had been more closely confined, they undoubtedly would have created sufficient pressure and propagated with sufficient rapidity to have given an explosive report. No attempt will be made in this chapter to give all the details of the explosions of this kind which have occurred. The authors have not had opportunity to investigate explosions in all types of industrial plants, but have confined their efforts more particularly to the grain industry, extending their investigations into other industries to give such assistance as might be possible, but especially to obtain information which would help in solving the general problem. Consequently the data which are given below regarding industries outside of the grain industry cannot be considered complete. In fact, all of the explosions which have occurred in the grain industry probably are not included in the list of explosions given below, since many of them were of such minor importance that they were not reported either to the government or to insurance companies. For instance, in one plant for a time, explosions were so frequent that hardly a week passed without at least one.

Fortunately, the grinding equipment had been installed in such a way that these explosions vented themselves to the outside and neither caused much damage to the plant nor delayed operations for any length of time. It would hardly be possible to include such explosions in this chapter, on account of lack of space, though they often furnish more information than the larger and more disastrous explosions.

Explosions in the various industries have been considered separately and details of the more important ones have been given. All known explosions where there has been a loss of over a hundred dollars in property have been included in tabular form with brief data. For much of these data it was necessary to depend upon published articles, insurance

reports and brief statements in the trade journals, but in all of the explosions listed to have occurred since 1913, a personal investigation was made, and the results of these investigations are given in the abstracts which follow.

EXPLOSIONS IN FLOUR MILLS.

In 1895, the Office of the Insurance Monitor of New York published a small book entitled "Spontaneous Combustion and Dust Explosions."[1] In the division on dust explosions a brief statement is made regarding several explosions in different industries up to the date of publication. It is interesting to note that as early as 1864 a flour mill was destroyed by a dust explosion which started from the ignition of the dust by an open flame. The miller of the Star Mill at Mascoutah, Ill., was running his mill during the night, grinding middlings. Toward morning the middlings became clogged in the middlings box and the miller went up to jar them down as he had often done before. Placing his small oil lamp on a beam just behind and above his head, he opened a slide in the box. As he thrust in the shovel, the middlings ran down, creating a cloud of dust. When this dust reached the lamp it was ignited instantly and a sheet of flame spread through that section of the mill. The fire which followed spread so rapidly that the mill was soon totally destroyed. Fortunately the only injuries the miller received were the burns on the exposed parts of his body.

An explosion is reported to have occurred in the Nicolin Mill at Jordan, Minn., in 1875. It was of such force that the roof of the mill was blown off and the mill destroyed.

On April 2, 1875, an open lamp ignited the dust in the middlings chest of a flour mill in Evansville, Ind., causing an explosion which destroyed the mill. Following an investigation, it was stated that during the 20 years preceding 8 flouring mills, 4 frame and 4 brick, had been built and operated in Evansville and of these 3 frame and 3 brick had been burned. The remaining frame building had been on fire twice within the preceding 3 months.

In 1877, a mill in Rochester, N. Y., was partially destroyed by a dust explosion and fire which started when one of the proprietors thoughtlessly put an open lamp into the purifying box. Only the lower portion of the mill was saved.

An explosion occurred in 1878, in a mill at Baldwin, Wis., when the plant was not in operation. A perpendicular chute had become clogged in some way and one of the men started to punch it out from above. He lowered a lantern into it to see if it was clear. An explosion resulted, in which the man was severely burned, but on account of the clean condition of the mill it did not propagate throughout the plant, though a column of fire shot up out of the chute fully 20 feet in height.

During the same year two explosions occurred in a mill in Des Moines, Iowa, one of them passing up the leg of the elevator and burning a hole in the roof, while the other caused but slight damage. The causes are not given.

A large flour mill in St. Louis, Mo., was destroyed in 1881 by a general explosion of dust. It was caused by lightning striking the plant. In less than 5 minutes the whole structure was enveloped in flames and was soon destroyed.

On May 19, 1882, an explosion occurred in a Minnesota flour mill when the hand slide was opened to relieve one of the spouts which had become choked. A mass of flour shot out, filling the air with dust. This took fire from lanterns on the floor nearby. The men working to relieve the choke were severely burned, but the small fire which started was easily extinguished.

In 1885, as the propietor of a mill in Chicago, Ill., was going through the plant carrying an oil lamp, the chimney fell off and broke. Fearing an explosion of the lamp, he set it down on the floor and picked up a handful of dust expecting to smother the flame by throwing it over the lamp. An explosion, in which he

[1] By C. C. Hine.

was badly burned, resulted from the ignition of the dust. There was a slight loss to the plant.

On October 17, 1887, an explosion occurred in a mill at Council Bluffs, Iowa, when a workman introduced a lantern into the flour hopper which he was cleaning, to determine the condition of the hopper. Heavy brick walls were blown out, the roof of the cupola was blown off, and the mill was partially wrecked.

An explosion of a mixture of saw dust and flour, used in cleaning furs, occurred in a plant in New York City on July 2, 1889, as a result of which 4 men were injured and the building and contents were damaged to the amount of $1300. The dust was ignited by an open candle.

MINNEAPOLIS, MINN. Although explosions are recorded as having occurred earlier, the first explosion which attracted attention in this country is the one that destroyed the Washburn Flour Mills at Minneapolis, on May 2, 1878.[1] Eighteen men were killed, and 3 mills, Washburn "A", Diamond, and Humboldt, were completely destroyed by a series of explosions. A number of the surrounding buildings were burned by the fires which followed, and there was extensive property damage. At the suggestion of the coroner, Professors Peck and Peckham, of the University of Minnesota, conducted special investigations in an effort to determine the cause and circumstances under which the explosions occurred. It was concluded that the fire had its origin in the east side of Washburn "A" mill, where 6 runs of stones grinding middlings were exhausted into a spout leading into the dust room. Evidently one of these 6 sets of stones ran dry and a train of sparks ignited the dust; or foreign material, such as iron, passed through the stones, striking sparks. After smoldering for several minutes, the fire burst into a blaze which ignited the dust in the conveyors and the dust room, causing it to explode. The explosion, starting in Washburn "A" mill, spread to and destroyed both the Diamond and Humboldt mills. Professors Peck and Peckham, who conducted extensive experimental work, were able to ignite various types of mill dust and stated that all the materials except the coarse bran burned with excessive rapidity when ignited.

CLEVELAND, OHIO. A dust explosion occurred in a Cleveland, Ohio, flour mill in September, 1888[2]. Two men were killed, several others were injured and the entire plant was destroyed by fire. It is stated that during the night one of the workmen went into a bin with a lantern to shovel bran. Exhausting into this bran bin was an old-style dust room, into which dust was blown from the purifiers. This dust, together with that created by the dropping of the bran 30 to 40 feet, into the nearly empty bin made a dense dust cloud in the bin. It is thought that the workmen removed the bottom of the lantern in order to raise the wick to obtain better light, and that the open flame, coming in contact with the floating dust, ignited it and caused the violent explosion and fire.

LITCHFIELD, ILL. On March 21, 1893, one of the most violent explosions on record occurred in a large flour mill at Litchfield, Ill.,[3] 30 minutes after a fire, which was still burning, had started in one of the elevators. Due to the fact that there were no men at work at the time of the explosion, the loss of life was limited to one employee, who attempted to enter the mill to recover his tools. The total loss was estimated at $500,000.

The explosion did extensive damage to surrounding property, and the shock was felt throughout the entire town of Litchfield, and for many miles around. It was described as being a "terrific report that shook the earth, hurled down chimneys and broke many panes of glass in the houses and business places of the town." The mill building was 7 stories high and, according to the testimony of eye witnesses, seemed to be blown to pieces. Large timbers 12 inches square were thrown for some distance in the air, and the entire building was laid in ruins.

The cause of the explosion is not known definitely. It is thought that it resulted from the ignition of a cloud of dust which might have been stirred up

[1] American Journal of Science and Arts, 1878, vol. 16, p. 301; Chemical Engineer, March, April, May, 1908, vol. 7.

[2] American Miller, vol. 16, p. 689.

[3] Northwestern Miller, March 24 and 31, 1893; American Miller, April, 1893, vol. 21, p. 277.

by the action of the flames and falling timbers during the course of the fire. It is very probable that the support of the dust or "stive" room may have burned and given way, throwing into suspension its contents of inflammable dust, and from this start the explosion propagated through the entire mill.

Boone, Iowa. An explosion occurred in a dust bin in a flour milling plant at Boone, Iowa, on September 18, 1899[1]. The dust and chaff which accumulated in a large bin for several weeks was sacked and hauled away when the mill was not operating. When the explosion occurred, a workman was inside this bin shoveling the dust into sacks, which were held just outside the only opening in the bin. A lantern hung on a nail within the bin is thought to have caused the explosion by igniting the dust stirred up by the workman.

Arkansas City, Kan. A disastrous fire originating from an explosion of flour dust occurred in a Kansas mill on June 17, 1903.[2] One of the employees lost his life as a result of burns received during the fire and the estimated property loss was over $150,000.

A workman, according to reports, went to examine the flour bins on the second floor. Each bin was provided with a small opening covered by a sliding door, through which the employee examined the flour and noted the conditions. As the workman raised the door of a bin, a terrific dust explosion took place and a mass of flaming flour dust shot through the opening. In an instant the second floor of the mill was afire, and the entire plant was destroyed. It is reported that a second explosion occurred while the fire was in progress which resulted in injury to one of the owners when he tried to enter the elevator. As no light of any kind was thought to have been used in examining the bins, the direct cause of the explosion was not determined.

Niagara Falls, N. Y. On June 21, 1906[3], a dust explosion in a flour mill in Niagara Falls, N. Y., occurred in the frame flour bins extending from the first to the fourth floors of the stone building. There is said to have been a light explosion in one of these bins. This did not appear to do any damage, merely lifting the trap in the top, but it stirred up considerable dust. This explosion was followed by another and much more violent explosion which did much damage. The sides were blown out of two of the bins, the floor over the bins was raised several feet, and the sprinkler equipment at this part of the plant was put out of commission. The cause of the explosion was not definitely determined.

New York City. An explosion of small proportions occurred in a flour mill in New York City on July 6, 1909.[3] It started in a wooden, dust-settling, screw conveyor trunk on the third floor of the mill, shortly after starting the machinery in the morning, and was of sufficient force to open the trunk at the joints. The explosion was first noticed by employees on the second floor when the doors of the rolls were blown open. No definite cause was assigned to the explosion, but it may have started in the rolls, caused by sparks from foreign material, and then propagated to the dust settling chamber. Due to the effective operation of the sprinkler system, the damage by fire was very slight, the total loss being under $200.

Portland, Ore. On September 16, 1909, a fire following a dust explosion destroyed one of the largest mills on the Pacific Coast, with a loss of about $300,000. The fire occurred on the fourth floor of the main flour mill building and followed an explosion of flour dust. A nail passing through the rolls produced sufficient sparks to ignite the flour dust and cause the explosion which spread through the dust collecting system and wrecked the upper floors. The flames from explosion and fire, due to the presence of dust, traveled so rapidly that the sprinklers did not open in time to check their progress. Four concrete grain tanks, between the main building and the engine room, acting as a fire

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[1] Northwestern Miller, Sept. 1899, p. 54.
[2] Arkansas City Daily Traveler, June 18, 1903; Northwestern Miller, June 24, 1903, vol. 55, p. 1313.
[3] N. F. P. A. Fire Record Data.

wall, saved considerable flour and most of the machinery in the engine room. This mill, at the time of its destruction, had a capacity of about 4,500 barrels.

Elkhart, Ind. On October 21, 1909,[1] the Harvest Queen Mill was destroyed by fire, originating from an explosion of dust on the fourth floor. The total loss was $50,000 including 18,000 bushels of wheat. The exact cause of the explosion could not be determined.

Arendtsville, Pa. An explosion which the miller stated occurred in the wheat-scouring machine of a mill in Arendtsville, Pa., on Sept. 13, 1913, threw sparks and fire in all directions. The entire plant was destroyed at a loss of $16,000.00. It was thought that foreign material, such as pieces of iron, got into the scourer.

Leavenworth, Kans. On November 1, 1913, two weeks after an attrition mill had been installed for grinding wheat screenings, an explosion of limited proportions occurred in a flour mill in Leavenworth, Kansas. There was no loss of life, and damage to the property was slight. The mill was installed with a metal bin directly under the grinding machines, into which the ground material was discharged. It was then conveyed to an elevator. At the time of the explosion there was not sufficient dust present to cause serious trouble, and the only damage done was a bulging out and loosening of the sides of this metal bin. The explosion made a loud report and filled the mill with smoke.

Long Island City, N. Y. On November 21, 1913, a fire resulting from a dust explosion destroyed the three-story brick building of a large macaroni plant. Workmen were burned badly about the hands and face.

It was concluded after an investigation that the explosion occurred in a conveyor and that it was caused by sparks from a stone or detached conveyor worm igniting the flour dust in the conveyor box.

Beatrice, Neb. The force of a dust explosion in a Nebraska flour mill on September 22, 1914, was so terrific that the west walls of the two floors of the building were blown into the river. The roof was raised and every window, including the sash, was destroyed. Fire broke out at several places in the mill, but was extinguished by the prompt action of the employees. The explosion occurred in a flour bin and the upper portion of the flour packer underneath, just after an employee had gone upstairs to determine the amount of flour in this bin. He would not acknowledge that he lighted a match as he opened the bin door, but a slightly burned match, which could hardly have gotten there in any other way, was found in the flour in the bin after the explosion. While this is only circumstantial evidence it indicates a possible cause of the explosion.

American Falls, Idaho. A small explosion which occurred in a milling plant at American Falls, Idaho, in May, 1917, was followed by a fire which destroyed a portion of the mill, causing a loss estimated at $60,000. The exact cause of the explosion is not known.

Benton, Pa. A Pennsylvania roller mill was almost completely destroyed by an explosion and fire on February 21, 1918. The loss was about $45,000. Between 7,000 and 8,000 bushels of wheat were damaged or destroyed together with smaller quantities of buckwheat, oats and rye. Two employees were slightly injured.

The first or initial explosion, a sort of a puff, was followed by two distinct and more violent explosions. Some of the witnesses claimed that the roof was observed to rise and then settle back. Flames appeared immediately at the discharge of the two cyclone dust collectors and on the top floor.

Careful investigations indicate that this was unquestionably a dust explosion, which took place in or around the cyclone dust collectors, but the cause of the initial ignition could not be definitely established. The mill apparently was running satisfactorily. There had been no choke-ups, hot bearings or open lights.

New Prague, Minn. An explosion of minor proportions occurred in a flour mill in New Prague, Minnesota, on April 7, 1918. Rye flour was being ground

[1] Northwestern Miller, October 17, 1909, p. 219.

at the time and the explosion occurred in one of the third-break rolls just as the miller had thrown the rolls apart and opened the door. It traveled through the dust-collecting system where a secondary explosion occurred and a small fire started. There was a distance of about 125 feet between the rolls and the dust collectors. The suction pipe was blown apart at some points, but no great damage was done as the fire was soon extinguished by the sprinkler system. The miller at the rolls thought that the explosion was caused by a piece of steel or some other hard foreign substance passing through the rolls, causing sparks which ignited the dust.

Cheney, Wash. On Sunday morning, April 14, 1918, a 300-barrel mill in Cheney, Wash., was totally destroyed by an explosion and fire. The loss was $300,000. The plant was not in operation at the time, but was being cleaned and made ready for the next week's running. Sweepers were at work, and it is said that they had finished sweeping the first, second and fourth floors and were working on the third floor at the time of the explosion. A man was babbitting a box on the first floor and two others were repairing a plansifter on the third floor. The explosion apparently started on the first floor and must have been caused by the open torch of the workman babbitting the box, as the men on the third floor saw the smoke coming from below. The workman doing the babbitting claimed that he heard a noise and looking around saw a cloud of grayish black smoke and a mass of flames immediately surrounding him. It was with difficulty that he got out of the building.

Memphis, Tenn. One man was severely injured and a loss of several thousand dollars worth of property and foodstuffs was sustained by a mill in Memphis, Tennessee, in an explosion which occurred in an elevator on October 13, 1919. The first explosion was described as sharp and intense and was followed by a second heavy muffled explosion. The top of the elevator was blown out and fire started which, however, was soon under control.

Boissevain, Manitoba, Can. A flour mill in Boissevain, Manitoba, Canada, was partially destroyed on the evening of December 6, 1919, by an explosion of flour dust which occurred when one of the packers went to the bin to determine the amount of flour. He opened the door of the bin and struck a match. An explosion took place immediately and propagated up through the stairway to the floor above, where there was a second explosion near the top of the mill. The brick wall on one side of the mill was blown out and the other walls were partially wrecked. The manager fully believes that it was due to its cleanliness that the mill was not totally destroyed, as after the explosion fully 25 fires in almost every portion of the plant were extinguished. The loss was about $6,000.

Denver, Colo. On January 20, 1920, a flour mill in Denver, Colorado, was damaged to the amount of $100,000 by an explosion which apparently started in the dust-collecting system. It was thought that it was due to the ignition of the dust in the fan by sparks caused by the striking of the blades of the fan against the steel casing. However, much of the evidence indicated that the explosion started in one of the rolls, as the doors were blown off and the inner section of the dust-collecting system leading from this roll was scorched, showing that the explosion had propagated through it. Although the blades of the fan had been riding on one side and rubbing the casing, more thorough investigation seemed to indicate that the explosion must have been caused by sparks struck by foreign material passing through the rolls, but it was not possible to determine definitely just at what point the explosion may have occurred. However, it propagated through the entire dust-collecting system and out into the plant, blowing out some sections of the building and, together with the fire which followed, partially destroying the mill. Fortunately none of the workmen in the mill were seriously injured, although some of them sustained slight burns.

Kansas City, Mo. A dust explosion of unusual interest occurred in a flour mill in Kansas City on March 15, 1922. Flour millers were especially interested in determining the cause of this explosion because of the fact that it occurred in a modern flour mill equipped with the latest type of machinery and dust-collecting

apparatus. The evidence available indicated that the explosion undoubtedly occurred in the rolls, presumably caused by sparks from foreign material passing through the rolls. The extent of the explosion was limited and confined to the dust-collecting equipment.

ELEVATOR EXPLOSIONS.

Available records do not show that explosions occurred in elevators as early as in flour mills. This may have been due to the fact that large elevators are of more recent construction and also that small elevators of earlier years were of such construction that any pressure built up was quickly vented and the potential explosion was probably classified as a rapid fire.

One of the first elevator explosions on record occurred in Toledo, Ohio, on September 20, 1898. Ten people were killed, five were injured and the property was almost completely destroyed. It is stated that the explosion lifted the roof high in the air, and blew away portions of the sides of the elevator, and that in a very short time the entire structure was damaged by the fire which followed.

The explosion is reported to have been caused by an employee carrying a lantern into a dusty room. This case is similar to the explosion which occurred in a flour mill in Cleveland in 1888. Both show clearly the dangers of the practice of using lanterns around mills and elevators.

Richford, Vt. A very disastrous explosion occurred in an elevator in Richford, Vermont, on October 7, 1908. As a result of this explosion and the fire which followed, fifteen employees were killed and two women who were walking on the railway tracks outside the plant were so badly burned that they died soon afterward. The property was destroyed.

The plant consisted essentially of an elevator with a capacity of about 600,000 bushels, and a one-story warehouse about 720 feet in length and 80 feet wide. The elevator was being used as a feed mixing plant.

Witnesses stated that the first small sharp report was followed by one much longer and louder. The explosion was characterized by great force and violence. At the time of the explosion the plant had been shut down for a couple of days and the workmen were engaged in cleaning up the dust. Although grinding equipment was installed in part of the elevator, the officials of the company stated that no grinding was being done at the time of the explosion. The cause of the disaster was not definitely established, although it was thought it might have been spontaneous ignition, originating in the heated grain which was being removed from the bottom of one of the bins. Another theory was that a workman struck a match when the material was being removed from the bin.

Minneapolis, Minn. An explosion of unknown origin occurred in an elevator in Minneapolis, Minnesota, during the evening of September 16, 1909. The watchman had made his rounds less than an hour before the explosion and found no fire. The first explosion was small, but it was followed by a very heavy one, which carried the fire 30 feet through a structural-steel corrugated iron passage-way containing a large grain conveyor belt that operated from the working house to the tile bin house containing 51 bins. This caused a heavy dust explosion and a flash of fire in the tile-bin house, but the damage in this instance was confined to a slight loss of grain and the partial wrecking of the structural-iron roof supports and the corrugated-iron roof.

Philadelphia, Pa. Three explosions occurred in the boiler room and dust-collecting system of an elevator on April 25, June 30, and July 23, 1913. Dust was blown to a collector and then discharged into either of two boilers. The explosions seem to have occurred when the boiler damper was closed and when the fan delivering dust from the elevator to the collector was being stopped. Evidently the dust was fired by flames from the boiler going out through the dust feed pipe with a change of draft conditions due to the closing of the boiler damper and the shutting down of the fan. With the injection of a water spray into the dust feed pipes just before they enter the boiler and the arrangement

of a signaling system so that the boiler damper can not be closed when the fan is being stopped, the frequency of the explosions has been largely controlled.

Akron, Ohio. An explosion occurred on December 2, 1913, in an elevator in Ohio. No lives were lost, and damage to the property was small.

The explosion took place in an elevator leg used for transferring grain from one bin to another. The leg of the elevator on the first floor was blown off, and the head was blown apart. After the explosion the odor present resembled that following the discharge of a shotgun. This was quite noticeable on the first floor, and at the elevator head where the flames escaped. The officials thought that possibly a loaded cartridge had been thrown into the grain in shipment, and, due to the friction in handling it, had exploded and ignited the dust.

At the time of the explosion one of the men was using an electric extension light to look into the leg through an opening on the first floor. Later it was found that the lamp had been burned out. It was not determined definitely what relation this had to the explosion, but it is possible that this may have been the cause.

Galveston, Texas. Although a dust explosion which occurred in one of the largest elevators in the South on March 30, 1914, was violent enough to blow out the sides of the "spouting floor" of the building, no one was injured. The capacity of the elevator was about 1,000,000 bushels. Due to the fact that the automatic sprinklers operated immediately after the explosion, no damage from fire resulted. The greatest loss was caused by the grain being damaged by water from the automatic sprinklers.

The exact cause of the explosion could not be determined. One investigator concluded that it was produced by static electricity from the elevator machinery belt that had been very loose on account of the damp weather prevailing at the time of the explosion.

Weehawken, N. J. The conditions surrounding an explosion which caused about $50,000 damage to an elevator of 2,000,000 bushels capacity near New York City in July, 1915, are noteworthy. The explosion was confined to 5 all steel bins which formed part of a row along one side of the elevator. The tops of the bins were covered with 3-inch tile laid on steel cross-beams and covered with 1½ inches of cement. This covering was continuous with and formed the bin floor. The covering of each bin was provided with a manhole with an iron cover.

All evidence seemed to indicate that the explosion took place in the center one of the 5 bins, as grain was being run into only this one, and the entire covering was blown from 4 bins and about two-thirds from the fifth. It was evident that the greatest pressure was in the bins, but the force was also transmitted to the monitor or cupola which extended the length of the structure and about 75 feet above the roof. A large part of the walls of this cupola was blown entirely out.

A definite cause of the explosion could not be obtained. At the time of its occurrence, the center bin was nearly empty and grain, which came from a weighing hopper, had just started running into it, sliding fully 60 feet through an iron chute set at a slope of about 45 or 50 degrees, and falling over 70 feet to the bottom of the steel bin. It seems probable that the dust in the bin ignited by a spark created by some foreign material striking the steel cross-arm braces or the bottom of the bin.

New Orleans, La. The cause of the explosion in an elevator in New Orleans, La., Dec. 14, 1915, could not be determined definitely. Men on the bin floor stated that they saw flames shoot out from the bin openings and from the legs, but there was no propagation. The sprinkler system heads are thought to have been opened by the heat blast of the explosion.

El Reno, Okla. An explosion on December 21, 1915, at El Reno, Oklahoma, caused by a choke-up of wheat in an elevator leg, resulted in a loss of $2500. Fire spread to the bins and other parts of the building.

Peoria, Ill. The initial explosion in a large elevator on March 6, 1916, was followed by three minor explosions and fire spread rapidly over the whole plant. The roof of the building was blown over on to the railroad tracks. Fire was first noticed in one of the elevator legs which had become clogged and is supposed to have been caused by friction between the belt and the pulley which continued to revolve. The loss was $100,000 on the building and $500,000 on the grain.

Fort Worth, Tex. An explosion occurred in an elevator in Fort Worth, Tex., on Mar. 9, 1916, during the process of grinding kafir corn. To grind this hard grain finely the rolls had been brought too close together, it is thought. Either a foreign substance passed through them, striking fire, or the rolls at some rough place hit together. It is interesting to note that the flash of fire from the bins set dust afire in jute bags some ten feet away.

Baltimore, Md. Seven men lost their lives and 22 were injured in an elevator explosion in Baltimore, Md., June 13, 1916. The loss of the elevator, damage to two vessels nearby and grain in elevator and aboard ship was estimated at $1,500,000. The explosion was caused by a choke-up in one of the elevator legs. As a result of a defective signaling system and a misunderstanding among the workmen, the location was not determined. The friction, developed at the head, burned the belt in two, allowing it to drop and stir up the dust, which was ignited by the burning ends.

Brooklyn, N. Y. An elevator containing over 800,000 bushels of grain awaiting shipment abroad was destroyed on October 13, 1917, as a result of dust explosions and fire. The total estimated loss was approximately $1,750,000.

The first indication of fire came apparently from No. 1 lofter. The elevator belt, which consisted of a combination of rubber and canvas, 363 feet long and 24 inches wide, had been handling corn for about an hour. The odor of burning rubber was noticed by men working on the scale floor but they delayed about ten minutes looking for its cause until they had finished running the bin. Then the bearings and motor were found to be cool, but the belt was riding over to one side. After discovering this the employees started down stairs to shut down the elevator when the initial explosion occurred which blew out the head of this lofter and part of the sides of the tower. The employees made their escape uninjured. A second explosion came less than a minute later, followed by flames. The entire building was destroyed with the exception of a section at one end.

Although the cause of the original explosion in the elevator head could not be definitely established, it was probably the result of the rubbing of the belt against the side of the leg or the friction of the belt on the pulley. The second explosion was caused by the ignition of the dust stirred up by the force of the first one.

Fife, Mont. An explosion occurred in the Farmers' Elevator in December, 1917. Shafting, pulleys and other machinery were blown through the cupola roof. The building was destroyed by the fire which followed. The elevator head had set-in bearings and the dust had piled high on the inside of the head. It is thought that one of the elevator buckets hit a nail.

Beach Grove, Ind. An explosion occurred in an elevator just after two watchmen had left the plant, on June 14, 1918. They had made their trip of inspection carrying lanterns as was customary at intervals during the night. The top of the workhouse was blown completely off. The workhouse and 30,000 bushels of grain were destroyed by the fire, the total loss being estimated at $300,000.

Portland, Ore. An explosion of dust in one of the spouts of an elevator in Portland, Ore., occurred on March 24, 1919. The damage was estimated at about $3000.

Milwaukee, Wis. On May 20, 1919, an explosion which undoubtedly originated in the boot or lower part of the front leg of the center elevator occurred in an elevator in Milwaukee, Wis., resulting in the death of three men, and serious injury from burns to four others. The explosion occurred during the handling of cottonseed meal. The loss on property and feed amounted to about $150,000.

PORT COLBORNE, ONT., CANADA.. One of the most disastrous explosions in Canada occurred August 9, 1919, at Port Colborne, in which 10 men were killed and 10 others were seriously injured. The loss of property was estimated at $1,500,000.

The force of the explosion was terrific, especially in that portion of the plant above the bins. Immense pieces of reinforced concrete, steel beams and parts of the roofing were thrown in some cases 150 feet. A barge being loaded at the side of the elevator was sunk by the mass of debris thrown on it. The fire loss was almost negligible as a result of the fire-resistive construction. The cause of the explosion was not definitely determined, but it is probable that it was a choke in one of the elevators.

KANSAS CITY, MO. The explosion on September 13, 1919, in a large terminal elevator at Kansas City, Mo., was one of the most disastrous of its kind that had ever occurred in the United States in a grain elevator, for the reason that in no similar disaster had there been so many lives lost. Fourteen men were killed, 10 injured and property to the amount of $500,000 was destroyed. A thorough investigation was conducted and consideration given to the various theories as to the cause of the explosion without success in discovering the source.

All evidence available indicated that it originated in the basement in the vicinity of one of the receiving legs where workmen were busily engaged in cleaning. The spark that caused ignition might have been produced by smoking or by defective electrical devices, such as poor extension cords and unprotected bulbs and switches. The explosion propagated to all parts of the elevator, blowing out walls and shattering heavy concrete work as it went. The lines of communication from one building to another were, as usual, through the tunnels, runways and elevator shafts, the walls of which were generally destroyed.

MEMPHIS, TENN. On October 13, 1919, an explosion occurred in the elevator part of a plant in Memphis, Tenn. Fire was seen to flash from the top of the elevator immediately after the first sharp report. No loss of life resulted, but one man was severely injured. Several thousand dollars worth of property and food-stuffs was destroyed.

CHICAGO, ILL. The explosion on March 19, 1921, in the North Western Elevator at South Chicago, Illinois, attracted more attention to the subject of dust explosions than any other occurrence because of the great damage done to a structure which was considered so safe that insurance was unnecessary. As a result of the explosion 6 men lost their lives, several were injured and property to the extent of $3,000,000 was destroyed. The shock was felt for many miles, breaking windows in business houses five miles from the plant.

Because of the fact that all the employees who were in the elevator at the time were killed, it was impossible to determine definitely the cause of the explosion. However, after a thorough investigation of the wrecked elevator and consideration of the statements made by company officials, employees and eye witnesses, it is believed that the explosion was caused by fire in one of the driers. The cleaning of the garners above the driers created a dust cloud through which the flame propagated to the basement of the work house where the first heavy explosion took place.

The river house was badly damaged, part of it being blown into the water. Close inspection of the storage section revealed the fact that, in addition to the complete destruction of bins at the southeast corner, there was extensive damage to the concrete construction everywhere. The force of the explosion, unbelievable as it is, had evidently been sufficient to lift the huge loaded concrete bins (about 300,000 tons) from their foundations and to move them from their original positions. About 40 bins were shifted at the northeast corner nearly half a foot. The structure above the storage bins was totally destroyed, being twisted and bent in such a way as to necessitate complete renewal.

BALTIMORE, MD. An explosion that injured 3 men but caused little property damage occurred on the afternoon of July 5, 1921, in an elevator at Port Covington, Baltimore, Md. The fact that this elevator was free from dust accumulations and generally very clean prevented more extensive damage. The cause is

believed to have been sparks from static electricity or from foreign material in the grain being handled. The elevator had been given a thorough cleaning a short time before the explosion occurred. The minor extent of this explosion indicated the value of removing the dust from the plant and not permitting it to accumulate.

MONTREAL, QUEBEC. On October 27, 1921, an explosion of minor proportions occurred in a large terminal elevator in Montreal. The explosion originated in one of the elevator legs during the handling of corn and was thought to have been caused by sparks in the lofter leg. The resulting fire was soon controlled and the damage limited to approximately $11,000.

FEED AND CEREAL MILLS.

Another class of grain-handling plants which have been subjected to explosions is that in which various cereal products and feeds are manufactured. These plants have been classed together because in the manufacture of cereal products, feeds are a necessary by-product. As far less care is taken in precleaning grain for the manufacture of feeds than for the manufacture of food products, and as the material is subjected to a much more rapid and severe treatment in grinding, the hazard of the process is not only increased by the production of sparks but by the extra dust created. A number of minor explosions have occurred in such industries, and consequently unusual precautions are taken in many plants. In one plant hardly a week went by that there was not at least one explosion in a grinding machine and often there would be two or three in one day. Consequently, the machinery was so installed that these explosions would readily be vented to the outside air, and no damage would result except in the loss of a small quantity of burned product. Only the more important of these explosions will be listed and described.. Small explosions, caused by sparks struck by foreign materials passing through feed grinding machines have frequently occurred in cereal mills in the United States and Canada.

CEDAR RAPIDS, IOWA. A very disastrous fire following a dust explosion resulted in the complete destruction of a large cereal plant in Iowa, on March 5, 1905. One employee lost his life, three were injured and the property damage exceeded $1,000,000. The dust explosion, which started in a machine during the grinding of oat hulls, was caused by the ignition of the dust cloud by sparks from foreign substances entering with the grain stream. One of the mill attendants stated that he heard a hard substance strike the plates about the time the explosion took place.

The explosion appeared to originate in the conveyor line under the machine and then to travel through it to an adjoining elevator leg from which it propagated into a storage bin. The estimated property loss is one of the largest on record. This was one of the first big disasters of this nature in the cereal milling industry.

SHADYSIDE, N. J. An explosion occurred in a glucose plant in New Jersey on May 22, 1906, in a room located on the fourth floor of the building and used solely for filling the bins below the floor with dry "Indian Meal" feed. This feed, said to be light and dusty, was brought to the top floor in frame-enclosed and sprinklered bucket elevators, and was then carried to the bin room by four overhead screw conveyors encased in unlined frame boxes located 10 feet above the floor.

The report of the insurance inspector contains the following statement: "This was a dust explosion, started, presumably, by a spark from some foreign substance in the screw conveyor." It was said that the room was more or less filled with dust from the feed falling about 10 feet to the floor. The fire marshal, who was 50 feet from the building when the explosion occurred, said that he "saw the roof rise and the wall facing him blow out: then the roof settled back." One man was killed and the property loss resulting from the explosion and fire following amounted to about $75,000.

BUFFALO, N. Y. On January 4, 1910[1], an explosion occurred in a cereal mill in Buffalo, N. Y., which resulted in the loss of five lives, injuries to seven others

[1]American Miller, vol. 33, p. 333.

and property loss of about $118,000. The explosion occurred in the evening and at a time when business had been suspended for a few days. Consequently the machinery was not in operation. It was reported that the plant had been cleaned thoroughly. The weather was cold, the temperature being below zero. Owing to the complete destruction of that part of the plant in which the explosion occurred, the cause was never definitely determined.

Granite City, Ill. A big explosion partially destroyed a section of the elevator building of a corn products plant at Granite City, Ill., on August 7, 1910. Two men were killed and 7 others were more or less seriously injured. The greatest damage by the explosion was in the elevator building, although it was very evident that the origin of the explosion was at a point some distance away and in another building. Gluten feed, which is manufactured from the germ of the corn after the oil has been removed, was being ground in an attrition mill. The clogging of the feed to the mill or the passing of foreign material between the blades created sparks which ignited the dust within the grinding machine and caused a blaze and minor explosion to be carried fully 375 feet through a pneumatic conveyor to a cyclone dust-collector at the top of the feed elevator 140 feet above the attrition mill. This collector and the entire upper portion of the plant were blown apart by a secondary explosion which resulted from the stirring up of the dust by the explosion in the collector.

Buffalo, N. Y. The most violent explosion of grain and cereal dusts in this country in recent years occurred in a feed grinding plant in Buffalo, N. Y., June 24, 1913. The explosion was followed by a very disastrous fire which destroyed and damaged property some distance away. Thirty-three lives were lost and 80 people injured. The explosion occurred at about 4 o'clock in the afternoon of a very warm, sultry day, with the temperature at 90 degrees, and a humidity of 74 per cent. The explosion, described as consisting of two reports, one following the other, with the second report louder than the first, occurred when the mill was in the regular process of operation, that is, manufacturing feeds. Numerous theories have been advanced relative to the origin of the explosion, but the exact cause was not determined. An inquest of extended sessions was conducted by the City Court, in an effort to determine the cause and circumstances of the explosion. The decision of the Court, after examining 110 witnesses, many of wnom were employees, was in part as follows: "The testimony, without exception, has been that the plant on that day was in good working order, and that all ordinary precautions for the protection of the men had been taken. No evidence has been produced that would throw any light upon the cause of the accident, and I therefore find that the men whose deaths were caused by that accident, came to their deaths from fire originating from causes unknown."

This explosion awakened active interest among millers and grain men throughout the country and led to the initiation of the work now being carried on by the Department of Agriculture. The final conclusions reached indicate that the explosion originated in the feed-grinding department and probably was caused by ignition of oat-hull dust.

Keokuk, Iowa. An explosion occurred on the night of September 11, 1913, in a cereal mill in Iowa. Fortunately no lives were lost, but the property was damaged considerably by the explosion and the fire which followed. The explosion, characterized by a sudden puff, or report, followed by a body of flame and fire, took place in a section of the plant where oat hulls were being ground for feed. Here, also, the greatest damage was done. The conveyor lines from the grinding machine to the storage bins gave evidence of fire, and the explosive wave seemed to travel through this part of the plant. Although the grain is said to have been reasonably clean, it is thought that some foreign material may have been introduced into the grinding machine and produced sparks which ignited the dust cloud present. The flame thus produced traveled along the conveyor lines and elevator legs until the receiving bins or hoppers were reached, where the explosion occurred.

Buffalo, N. Y. One man was killed and seven others injured as the result of an explosion and fire in a feed mill in Buffalo, N. Y., Sept. 12, 1913. The property

loss was $180,000. It is believed that sparks from foreign material in the attrition mill caused the explosion as the grinding machines were on the floor on which the fire originated.

Fort Dodge, Iowa. An explosion took place in a cereal mill in Fort Dodge, Iowa, on November 6, 1913. Two men were burned very badly and the property was damaged considerably. Fortunately the explosion occurred during the noon hour, when most of the employees were outside the plant. The tender at the attrition mill was sitting near the machine, eating lunch, when he heard an explosion, described as light in nature, inside the machine. This was followed by a later explosion of a loud, rumbling nature, that shook the entire plant. The flames were carried by means of conveyor lines and elevator legs up into a large storage bin, containing but a small amount of ground material, and ignited the dust in suspension, thereby producing the violent explosion which followed.

Battle Creek, Mich. On October 30, 1914, a slight explosion occurred in one of the first-break rolls in a cereal mill in Battle Creek, Mich. It was described by the head miller as a puff of flame beneath the rolls, with only a slight report. The iron doors of the mill were blown open and flame shot out several feet into the room, but as there was nothing outside for it to propagate through or to set afire, this flame immediately spent itself. However, a flame continued to burn beneath the rolls until the feed was shut off and the mill stopped. The estimated damage was not over $5 as the only loss was some burned and charred flour.

At the time of the explosion the head miller was standing near the set of rolls. He heard something that sounded like a nail or screw coming down the spout along with the grain. The explosion happened just as it struck the rolls, the dust undoubtedly being ignited by the sparks struck by the foreign material as it passed between the rolls.

Davenport, Iowa. During January, 1915, a cereal mill in Iowa experienced two minor explosions within a period of 24 hours. Both were thought to have been caused by the ignition of dust on the interior of the grinding machinery (attrition mills) by the presence of foreign materials in the grain. Although the company had only been operating about three years, at least five explosions, minor in nature, had occurred. The explosions in 1915 were probably the most disastrous of any that had taken place.

Peterborough, Canada. A very disastrous explosion and fire occurred in December, 1916, in a large plant in Canada devoted to the manufacture of cereal food products. Seventeen persons lost their lives, sixteen were injured, and the property damage was estimated to be $2,000,000. The plant was apparently modern and up-to-date in every respect, being largely of fire-resistive construction and equipped with such safety devices as sprinkler systems, pneumatic separators, and dust collectors.

The explosion originated in the building in which oat hulls were ground, and the resulting fire spread through the entire plant, destroying it completely. The fact that the explosion originated in the building in which the grinding machines were located was established definitely by the testimony of survivors. As this building adjoined the boiler room, the first report led to the belief that one of the boilers had exploded. However, the boilers were found to be intact after the explosion, thus eliminating this supposition.

The machines, utilized in preparing cattle feed from oat hulls, were of the direct-connected motor driven, attrition-mill type. Although generally considered safe in every way, it was stated that flashes of fire had been observed to occur in the mills from the time these machines were originally installed. These flashes started no fires of serious proportions and did very little damage. A spark struck by the passage of foreign material through the grinding machine was undoubtedly the cause of this explosion.

South Bartonville, Ill. It is thought that an electric spark ignited the dust and caused the explosion and fire which occurred Jan. 1, 1919, in the grinding and mixing plant of an elevator in South Bartonville, Ill. The estimated loss was about $750,000 to buildings and contents.

Portland, Oregon. An explosion occurred in the discharge spout from an attrition mill in which alfalfa meal was being ground in a plant in Portland, Oregon, on March 24, 1919. The explosion propagated into the elevator and dust collector drawing dust from the discharge spout. It is believed that the explosion was caused by foreign material passing through the plates of the attrition mill with the partially ground alfalfa. The superintendent of the plant stated that several small explosions from this cause had been experienced previously, but that this was the first which had occurred since the suction dust-collecting system had been installed to remove the hot air and relieve the pressure within the grinding machine. The fire which followed this explosion was soon brought under control. The damage was estimated at $3000.

Peterborough, Ontario, Canada. Two explosions, one unimportant but the other causing considerable loss, occurred in a feed mill in Peterborough, Can., on July 31, and August 18, 1919, respectively. The sprinklers opened on all of the eight floors and prevented excessive damage. The fire is supposed to have started in the grinders and to have been carried into the elevator.

Buffalo, N. Y. On September 12, 1919, a dust explosion occurred in a feed mill and elevator in Buffalo, N. Y. Three men were injured, one seriously, and property to the extent of $20,000 was damaged.

The walls of the fourth floor of the building were blown out, and the roof of the cupola was destroyed. It is said that the efficient operation of the automatic sprinkler heads, opened by the explosion, saved the plant from entire destruction.

One theory advanced as to the cause of the ignition of the dust was that a muslin cover over one of the motors was set on fire by sparks from the motor. When tested several days later, however, this motor operated in a satisfactory manner and gave off no sparks. The cover over the motor may have been burned by the fire after the explosion. From the evidence obtained it is believed that the fire started from some unknown cause on the first floor near an elevator leg and spread to the fourth floor where the greatest damage was done.

Brandon, Man., Canada. One man was injured and a loss of $10,000 was sustained in an explosion which occurred in the third or upper story of a flour and feed mill in Brandon, Man., Canada, on Oct. 21, 1920. Little damage was done by fire, but the force of the explosion blew out the north, east and west walls of the third story and the stock was damaged by water. One theory of the cause of the explosion is that the kiln used for drying oats became overheated and set fire to the dust in the small space between the top of the kiln and the floor of the third story.

Buffalo, N. Y. An explosion of ground oat hulls occurred at a feed grinding plant at Buffalo, N. Y., November 22, 1921, when an electric lamp was broken within the head of an elevator carrying the ground material to the top floor of the mill.

A workman was using the light to inspect the elevator which had not been discharging properly. In some manner the steel buckets of the elevator struck the lamp which was protected by only a light wire guard. When this guard was crushed and the lamp broken the hot filament ignited the fine dust and the explosion occurred.

This case has been of unusual interest because it substantiates the theory that unprotected electric lights are a fire and explosion hazard in dusty industries. The workman referred to above was only slightly injured in this explosion and was able to tell accurately what occurred. On account of the clean condition of the plant no fire followed the explosion and the property loss amounted to less than $4000.

STARCH DUST EXPLOSIONS.

A number of explosions have occurred in the manufacture of starches, but complete details of the earlier ones are not available. As starch is one of the more inflammable dusts, greater precautions are taken in the handling of it than is

necessary with many other products. Many of the explosions which have occurred in starch factories have started in the machines where the starch was being ground or pulverized, as was the case in a factory in Bradley, Ill., on March 12, 1901. The plant was almost totally destroyed with a loss of $230,000. Explosions also occur in the drying kilns of starch houses as in a plant in Waukegan, Ill., on February 24, 1904. The cause of this explosion is not known. It resulted in the loss of one life and the destruction of the plant with a property loss of more than $200,000. Explosions in drying kilns are often started by a small fire, occurring possibly when the starch becomes overheated or when flame or sparks get in from the fan or air-circulating system.

New York City. On December 20, 1877, a confectionery factory in New York City was the scene of an explosion which blew the building to pieces and carried fire to the premises adjoining on both sides, causing a loss of $119,950. Two of the workmen charged the origin of the fire to the upsetting of a lamp in the starch room, but a subsequent examination failed to verify this explosion hypothesis. The findings, however, were based upon the assertion that "starch was not used in such a way as to leave distributed the fine powder through the room," a statement which could not be verified after the explosion, but which seems to be contrary to the known facts in other candy factories. The boilers were intact and there seemed to be no satisfactory explanation for the disaster unless it was an explosion of starch dust, which was ignited by the flame of the lamp.

Grand Rapids, Mich. In January, 1883, there was an explosion of starch dust in a candy factory at Grand Rapids, Michigan. The windows in several stories were blown out, but the fire which ensued in the debris was quickly extinguished. The explosion occurred in the drying room in which were several wooden trays containing corn starch. The room was dark and a gas jet was kept lighted. One of the trays fell over, scattering the starch in every direction and filling the air with the dust. The instant the dust reached the gas jet the explosion occurred.

Waukegan, Ill. One employee was killed and damage of about $300,000 was caused by an explosion and fire in the dry starch kiln house of a starch and glucose plant in Waukegan, Ill., on Feb. 24, 1904. The cause of the explosion was not determined. The sprinklers were ineffective as the force of the explosion ruptured the pipes.

Oswego, N. Y. On September 28, 1907, an explosion occurred in a starch factory at Oswego, N. Y. It started in the cyclone feed to the starch grinding room and extended to the dust collector on top of the grinding room. The force created was sufficient to tear the roof off the building and to wreck the cyclone and conveyor pipes. A similar explosion occurred at this plant in July of the same year. The cause of these explosions could not be determined definitely. In both cases the damage was slight and the resulting fires were easily extinguished.

Providence, R. I. Two explosions on February 12, 1908, followed by fire, practically destroyed a starch and dextrine plant in Providence, R. I., and killed 7 people. The first explosion occurred on the premises of a ship supply company occupying a portion of the same building. Several minutes later the second explosion took place on the second floor of the part occupied by the dextrine company. This dust explosion did most of the damage and was followed by a serious fire. The fires in the dextrine kilns were banked at the time, and the only operation going on in the starch factory was that of packing.

Presumably the first explosion occurred among some of the inflammable fluids of the ship supply stock. It shook the whole premises sufficiently to impregnate the air in the building with starch dust. The fire, quickly reaching the dust laden rooms, caused a second explosion.

Roby, Indiana. On March 7, 1910, in Roby, Indiana, a violent explosion in a starch factory killed four and injured ten workmen. Although the theory was advanced through the press and the technical journals that the explosion was due to overheating a "starch kiln," the evidence indicated that the initial explosion originated in one of the starch pulverizing mills in the grinding house and then propagated through the conveying system to an adjoining building where the violent

explosion occurred. It is thought that the source of ignition came from sparks produced by foreign material entering between the plates of the grinding mill.

Lansdale, Penn. Four men were seriously burned, and a plant in Lansdale, Penn., engaged in manufacturing cassava flour, was nearly destroyed by an explosion which occurred in a drier on April 16, 1911.

The driers, which contained a residue of stock on the bottom, possibly several inches in thickness, were shut down at 4 o'clock in the afternoon, and on the following morning a number of workmen began to make certain repairs. During the work the electric lighting current was shut off, and the men secured two oil lanterns which were taken inside one of the driers. A few minutes later the explosion took place, due to the ignition of the starch dust by the open flames of the lanterns.

Waukegan, Ill. A very disastrous explosion occurred in a starch factory in Waukegan, Ill., on November 25, 1912, resulting in the loss of 14 lives, injuries to 19 other employees and a property loss of over $100,000. The cause of the explosion was not definitely determined, but the general conclusion of officials at the plant seems to be that an employee struck a match in the starch house, causing an ignition of the very fine dust from the driers. The explosion started in the starch drying house and propagated throughout the plant. It was so terrific that its effects were felt for some distance from the plant.

Edgewater, N. J. A New Jersey starch and dextrine plant experienced disastrous dust explosions on two separate occasions, September 6, 1914, and December 21, 1915.

This plant consisted of a powdered starch department where the starch was dried and ground, a dextrine department in which the powdered starch was manufactured into dextrine products, and a dust-collecting house, a building located away from the remainder of the plant and containing two rooms, one for dextrine dust and one for dry starch.

It was believed that the September, 1914, explosion, which killed two and injured three men, originated in the revolving reels in the dextrine department. The flame and pressure burst out into the room. Three workmen nearby were burned. Flame traveled up through the pipe conveying the dextrine from the shakers to the floor above the reels where two workmen were burned. The flame was also drawn into the suction dust-collecting system, through which it propagated to the dextrine dust house, where a second very violent explosion took place, which completely destroyed both the dextrine and the dry-starch dust rooms. The flames and pressure from this explosion traveled back through the dust discharge pipe into the dry starch department, but fortunately this portion of the plant was not in operation and the explosion died out.

The December, 1915, disaster, which killed one man and injured eleven, and caused damage to property amounting to $25,000, appears to have traveled in the opposite direction. It originated in the dry-starch grinding plant and passed through the dust house and back into the dextrine department. The explosions occurred at about 8:55 A. M., two distinct reports being heard. The first was described as loud and sharp and of short duration; the second, as a long rumbling sound followed by a large body of flame. The brick wall between the dextrine department and the dry-starch grinding room was blown down, and this entire portion of the plant badly burned. Also the dust house was completely destroyed. Only slight evidence of violence and fire was present in the dextrine plant. The dextrine reel was not damaged in this explosion, but it gave evidence of fire.

The point of origin of the 1914 explosion seems to have been within the dextrine reels on the second floor. The cause of the ignition could not be established definitely, but previous experience led the officials to conclude that the dust was ignited by static electricity produced by the friction of the dextrine on the brass sieves. Provision had been made to remove the static electricity through a ground connection to the journal box. However, a few minutes before the explosion occurred, the bearings had been oiled and it is thought that this layer of oil served as an insulator and allowed the charge to build up in the reel until it discharged and ignited the dust.

The exact cause of the 1915 explosion was perhaps more of a mystery, as its exact point of origin could not be determined. The most plausible explanation seemed to be that it started in a starch reel, and that it was caused by static electricity.

The ground-wire connections on one of the brass reels in the powder mill were found broken, making a favorable condition for the accumulation of static electricity. The weather conditions, unusually low humidity and dry cold air, were likewise favorable for the generation and accumulation of large quantities of static electricity.

Argo, Ill. Two workmen were seriously injured in an explosion in a starch factory March 12, 1919, in Argo, Ill., believed to have been caused by the breaking of an electric light bulb which had been lowered into a starch bin. The property loss was not large.

Cedar Rapids, Iowa. On May 22, 1919, in the early evening, a disastrous dust explosion occurred in a starch factory at Cedar Rapids, Iowa. Forty-three men lost their lives and 30 more were injured. The property damage exceeded $3,000,000.

The force of the explosion was so terrific that buildings a mile from the scene of the disaster were damaged. The damage to plate glass alone in the city exceeded $150,000. The entire plant was wrecked and that portion which was not destroyed by the explosion was damaged by the resulting fire.

The exact cause of the explosion could not be determined as all the direct evidence had been destroyed. After the investigation, however, it was concluded that it originated in the dry-starch section of the plant. In the examination of machines to determine whether the ignition came from any mechanical source, a tear in a new screen of one of the grinding machines was discovered. This tear indicated that foreign material had passed through the screen and that the conditions in the interior of the machine were not normal. It was concluded from this evidence that the spark which ignited the dust might have been produced by foreign material entering the machine. It is also probable that the original ignition then propagated through the milling system and caused the disastrous explosion.

RICE MILLS.

Explosions in rice mills have not been so frequent as in other types of mills, probably on account of the large percentage of ash in the rice hulls. However, minor explosions have occurred in the manufacture of rice starch and flour, and also in the polishing of rice where dextrine was used as a polishing material. The dusts created have been found to be much less inflammable than many other types of milling dusts.

New Orleans, La. On April 7, 1918, a New Orleans rice mill was destroyed by fire as a result of a rice dust explosion. The total loss was estimated at $30,000.

The explosion originated from sparks produced in an attrition mill which was being used to grind rice hulls. Though not violent, it was of such a nature that the fire seemed to propagate instantly throughout the plant in the burning dust suspended in the air.

The dust cloud present in and around the attrition mill may have been ignited if the magnets were not working and a piece of foreign material or steel entered the mill and produced sparks, or if the steel discs of the mill were set so close that they would strike and produce sparks when the machine was empty.

MALT DUST.

Some of the earlier explosions on record have occurred in breweries or malt houses. One of the first ones in this country occurred in Ehret's Brewery, in New York City, on July 30, 1881[1]. The explosion started at or near the head of

[1]Scientific American, August 20, 1881.

the elevator, which was carrying crushed malt from the crushing machines to a distributing chamber in the top of the building. It was probably caused by the ignition of dust in the crushing or grinding machines. The first explosion was followed by two or three secondary explosions and these by a fire which nearly destroyed the plant. The roof of the building was lifted and the walls were partially destroyed. Another small explosion occurred in this same plant on July 4, 1880, when the dust in the malt mill was ignited by a match going through the mill. The explosion propagated in the elevator. The loss from the explosion and fire was $2000. The superintendent stated that similar explosions had been caused by pebbles or pieces of metal passing through the machines.

In May, 1889, another brewery in New York suffered heavy loss as a result of an explosion in the grinding machines in which malted barley was being ground, and in July of the same year a slight explosion occurred in still another brewery in the same city and from a similar cause. In this last case the explosion propagated into the hoppers, but very little damage was done.

On July 18, 1901, an explosion started in a malt house in Portsmouth, N. H., in the hopper under the malt grinding machine, and spread through the elevator to the malt bins. The force of the explosion blew off a portion of the roof of the building, but the fire which followed was soon under control and the loss was only about $15,000. The cause of the explosion is not known, but it is thought to have been started by foreign material passing through the grinding machine. A similar explosion occurred in another brewery in Portsmouth on August 11, 1911. In this case the explosion was drawn into the dust collecting system and the greatest damage was done in the vicinity of the dust collector. The loss was about $2000.

A brewery in Springfield, Mass., was damaged to the amount of $1600 on September 13, 1907, as a result of the explosion and fire which occurred in the malt mill. The explosion propagated through the elevator legs to the malt bin, where the greatest damage was done. A similar explosion with small loss in a brewery in Boston, on July 23, 1908, was caused by foreign material passing through the malt mills. It is thought that some foreign substance got by the magnets installed for the removal of metal before the malt went into the grinders. A similar explosion occurred in another Boston brewery on May 31, 1911, caused by foreign material passing through the Dobbler mill.

On September 13, of the same year, an explosion occurred in a brewery in San Francisco, also caused by sparks struck by foreign material in the malt mill. A smoldering fire started in the hopper under the mill and was partially smothered by the ground material. It was conveyed to a larger receiving hopper where it caused an explosion of accumulated dust.

Chicago, Ill. On October 7, 1916, the seven-story grain elevator of a malt and grain company in Chicago was wrecked by fire and explosion. Four men were burned and injured and a loss of about $25,000 was sustained by the concern. The cause of the explosion could not be ascertained.[1]

Milwaukee, Wis. During a fire in the elevator of a malt company in Milwaukee, Wis., on October 15, 1916, an explosion occurred which blew out the walls and spread the fire. Doubtless a dust cloud was formed by falling timbers or by a draft and was ignited by the flames. The origin of the fire is unknown. The elevator, with its contents of about 500,000 bushels of malt and barley, was completely destroyed. The building alone was valued at $150,000.

SUGAR DUST EXPLOSIONS.

Sugar is one of the more inflammable of the mill dusts, but the early records disclose no accounts of serious explosions as having occurred in the sugar industry. This may be due to the fact that sugar has not been pulverized until the last few years, and that but a small amount of dust is created in the handling of the rather coarse product. However, on August 20, 1891, an explosion occurred in a Phila-

[1] American Elevator and Grain Trade, Oct. 15, 1916, p. 266.

delphia refinery, as a result of the ignition of dust by open gas lights. Grinding, sifting and handling of powdered sugar, and the use of the open flame as a source of light were the direct causes of this explosion. The fire spread rapidly but was soon under control.

BROOKLYN, N. Y. On April 28, 1911, an explosion completely destroyed the sugar dust house located on the roof of a sugar refinery in New York. This dust house was connected with the granulated sugar driers and was constructed of light material for the purpose of releasing the pressure created by a possible explosion. The cause of the explosion was not definitely determined, but it is thought that the dust was ignited by a spark produced either by one of the blower fans which exhausted from the granulated sugar driers to the dust house or by the entry of foreign material in one of the pulverizing machines. These pulverizers did not directly connect with the dust house but exhausted into dust collectors located on an upper floor. It is stated that the top of one of the pulverizers was blown off. The fire which followed the explosion destroyed part of the plant.

PHILADELPHIA, PA. The damage resulting from an explosion of sugar dust in a Philadelphia sugar mill on February 27, 1914, was slight. The explosion occurred in the building where the granulated sugar was being pulverized. The cause was said to be the breaking up of the lignum-vitae button in one of the powder mills. Excessive friction, accompanied by heat, was produced, which in turn ignited the sugar dust in the machines and caused the explosion. It propagated into the receiving bin and bolting system but the force was slight and very little damage resulted from fire on account of the prompt operation of the sprinkler system.

NEW YORK CITY. In February, 1914, an explosion occurred in the sugar pulverizer of a chocolate factory located in New York City. One employee was badly burned and the property damage was confined almost entirely to the machinery. Previous explosions of this nature had been experienced at this plant. Sprinklers, operating directly over the machine at the time, extinguished the fire resulting from the explosion before much damage was done. No explanation could be given for the explosion other than that it was caused by a spark originating from foreign material entering the machine or by a hot bearing. There is also a possibility that static electricity was the cause as had been the case with the same machinery grinding other materials.

BROOKLYN, N. Y. A portion of a New York sugar refining plant was destroyed by an explosion and fire on June 13, 1917. Twelve persons lost their lives and 24 were injured as a result. The property damage amounted to over $1,000,000 and included the destruction of 70,000 bags of raw sugar.

It is believed that the explosion originated in the sugar pulverizing machinery on the seventh floor of a building which served as a warehouse and packing department. It blew out portions of the walls. The workmen had little chance to escape, consequently those who might have known the real cause and point of origin were buried in the ruins. The fire which followed spread so rapidly and destruction was so complete that all material evidence was also destroyed. The rapid spreading of the flames was permitted by the destruction of the sprinkler system when the explosion occurred.

Many theories were advanced in explanation of the cause of the explosion, including spontaneous combustion, naked flames, bomb plots, and sparks struck by metal in the grinders. Careful investigation indicated that the explosion originated in the sugar pulverizing department and that it propagated to the dust cloud present in the empty sugar bins, and then throughout the various parts of the plant.

CHICAGO, ILL. An arc from an electric switch which ignited the sugar dust in the air is assigned as the cause of an explosion which occurred June 16, 1920, in Chicago. Fire followed. There was also a small explosion and fire in the same plant on Feb. 2, 1921, supposed to have been caused by sparks from foreign material.

WOOD DUST.

It would hardly be expected that extensive explosions would occur in saw mills or wood-working plants of the ordinary type, as these are largely of open construction. Often the work is carried on under a simple roof or other slight protection from the weather, without enclosed walls or building. However, several explosions have occurred. As early as November, 1874, eleven workmen were seriously injured in an explosion in a wood-working plant in Detroit, Mich. A brick flue extending through several floors of the building had openings on each floor into which refuse such as dust and shavings was put, to convey it to the furnace room. A steam pipe passed through this flue about eight feet from the furnace room floor. A fire starting at this point had just got under way when a quantity of dust and shavings was thrown down the flue. These were ignited and the explosion resulted.

In May, 1880, an explosion of dust from the finishing room in a wood-working plant in Appleton, Wis., caused considerable damage to the plant. The dust, which was created in the polishing or sanding of wagon wheel spokes, accumulated on rafters and beams. Some of it fell into some live coals that had accidentally fallen out of the stove onto the hearth. Another explosion caused by the ignition of dust in the engine room caused the partial destruction of a plant in Columbus, Ohio, in 1886, and the injury of one man.

A new dust collecting system in a wood-working plant in Fitchburg, Mass., was being tried out on February 7, 1906, and dust was being blown to a collector having a feed pipe, directly into the boiler room. Dust which had worked into the system was blown down into the boiler room as the new equipment was started. The furnace doors being open at the time, the dust ignited and caused an explosion which propagated through a portion of the plant.

On November 25, 1913, a plant in St. Louis was partially destroyed, the roof being blown from the one-story structure, as a result of an employee carrying an open lantern into the shavings house.

An explosion, interesting because so unusual, occurred in 1915 in a wood-working plant in the South. Hardwood handles for knives were being polished and the dust was drawn away in a dust-collecting system. Sparks from an emery wheel more than 15 feet away were drawn into the dust-collecting system and an explosion resulted.

Wausau, Wis. An explosion of dust in a boiler furnace blew the fire back into the shavings vault of a woodworking plant in Wausau, Wis., April 18, 1901.

Barber, Calif. An explosion of sawdust occurred at Barber, Calif., on August 6, 1910, wrecking the power house, three of the walls being demolished, and the roof blown off. Two men were killed and several persons severely injured.[1]

Philadelphia, Pa. One person was killed and one injured in an explosion which occurred in a woodworking plant in Philadelphia, February 5, 1913. The explosion started from an unknown cause in a mill grinding wood refuse, and propagated to the vault.

Nashua, N. H. A fire and explosion, which seemed to originate in the dust room, resulted in several hundred dollars damage to a wood-working plant in Nashua, N. H., on June 11, 1913. Walls were cracked and windows blown out. It is thought that the fan which blew the dust into the room was such a distance away that the trouble could not have started there, and the most plausible explanation given seems to be that a piece of oily waste within the dust room became ignited and fired the dust.

New Albany, Ind. Fire caused by an overheated journal was discovered by an assistant engineer on the first floor of a woodworking plant in New Albany, Ind., August 1, 1913. The accumulation of oil and sawdust on a bearing was dripping fire or sparks into a pile of sawdust on the floor. When the assistant engineer located the small blaze he dashed water on the floor with such force that the burning sawdust was blown about and a dust explosion followed.

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[1] Engineering News, vol. 64, p. 189.

Camden, N. J. On October 27, 1914, wood dust exploded in the work shop of a talking-machine factory in Camden, N. J., but the quick action of the employees extinguished the fire which followed before much damage was done. The explosion which occurred in the wood shaving collecting system installed in the plant, probably was caused by fire from back draft in the pipes. The loss was about $6500.

Portland, Maine. An explosion of wood dust in the loft of a planing mill in Portland, Maine, in July, 1915, resulted in the death of one man and partial destruction of the plant. The cause of the explosion is not known, but it is probable that there was a back fire from the furnace into the dust collecting system.

Tacoma, Wash. A fire and explosion in a door factory in Tacoma, Wash., on July 17, 1917, caused a loss of between $110,000 and $120,000. The fire is believed to have started in the cyclone from sparks from the stack or a passing engine. Before it could be extinguished an explosion occurred which scattered the fire around the interior and over the roof of the plant.

Chicago, Ill. Several persons were injured in an explosion in a planing mill and box factory in Chicago, Ill., on November 8, 1920. The source is supposed to have been carbonized and glowing sawdust around a choked shavings feed pipe leading to the boiler. Workmen scattered the dust in poking through the pile of shavings. The property loss was small, although part of the roof was raised.

Buffalo, N. Y. No definite cause can be assigned for the explosion in a Buffalo woodworking plant which occurred March 3, 1921, about two hours after the mill had shut down for the day. As the automatic sprinklers were destroyed, the loss from fire was large—about $75,000.

MISCELLANEOUS DUSTS.

A number of explosions have occurred in many industries and, in fact, in almost every industry where dust is created in the handling or manufacture of products from a material which will burn. Among these are various dry food products, wood, cotton, cork, celluloid, spice, soap, fertilizer and sulphur dusts. A brief description of some of the more important explosions in these industries follows:

ALUMINUM DUST.

New Kensington, Pa. On November 5, 1917, a disastrous fire and explosion occurred in an aluminum works at New Kensington, Pa. Seven persons were killed, fifteen were injured, and a property loss of $175,000 was incurred. One explosion of dust or gas occurred when water was turned on burning powder. It was followed by a dust explosion a few minutes later in the underground heating duct. The fire was believed to have been caused by sparks from a sledge hammer falling into fine dust.

Manitowoc, Wis. Six girls lost their lives and four others were seriously injured in an explosion of aluminum dust in a manufacturing plant at Manitowoc, Wis., on February 26, 1920. The property loss was slight because the fire which followed the explosion was readily extinguished. The explosion occurred in the finishing department where a satin finish was put on small aluminum pieces, by holding them against a rapidly revolving wire brush. Aluminum dust is created in the process and in this plant it was drawn away from the polishers into a suction system which discharged into the open air. A heavy piece of steel wire, No. 7 B. & S. gauge, fell into the exhaust pipe and got into the fan, striking sparks which ignited the dust. The explosion propagated back through the suction system and went out into the room, causing the explosion which was so violent that it was heard at least two miles from the plant.

CELLULOID FACTORY.

Leominster, Mass.—On September 3, 1913, an explosion in a celluloid and horn pin factory in New England occurred in a room where hair ornaments were

being worked into the desired form on burring and beveling machines. Attached to each one of the machines was a suction pipe connected with a dust-collecting system to draw away the dust created by the machines. Apparently a spark from one of the machines was drawn into the blower pipe. The fire resulting from the explosion was controlled by the sprinkler system.

COCOA DUST.

Boston, Mass. A cocoa dust explosion occurred in a cooling room of a chocolate company in Boston, Mass., on March 30, 1914. Ground cocoa was dropped through a six-inch pipe from the pulverizers on the floor above and discharged into an open hopper back of a Sturtevant blower. It was then blown through 12-inch cooling pipes to a system of cyclone dust collectors, which discharged the heavier portions, while the air and lighter dust were led through 12-inch pipes to other cyclones and to a small cloth-covered frame dust catcher in the corner of the room. It was concluded that the explosion might have been caused by the ignition of the cocoa dust in the blower system by sparks struck by foreign material passing through the fan. The force of the explosion opened the heavy wooden door into the packing room adjoining, partially blew down a wooden partition, blew out some of the windows, bent some of the sprinkler pipes and lifted the wooden floor above. No damage was done by fire except to the cloth on the dust enclosure.

No definite cause for this explosion could be found, but tinsmiths who were working on the spouts are reported to have found a match box. The matches might have been ignited as they passed through the fan and caused the explosion. This report could not be verified. Static electricity has also been suggested as a possible cause.

Burlington, Vt. The plant of a milk chocolate company in Burlington, Vt., was completely destroyed April 25, 1918, by a fire that followed a dust explosion in which 3 men were killed and 1 injured, and $750,000 worth of property was lost, including 8 carloads of granulated sugar. The company at the time was working on a million dollar order for the government.

A cyclone dust collector, located in the packing room, was enclosed in a dust room with cloth covering to catch any dust carried out by the exhaust. It had no direct outlet to the open air. This dust collector discharged through a fan to another cyclone dust collector located in the basement and incased in a perforated metal cylinder with cloth covering to catch escaping dust. This collector also had no outlet to the open air.

In the process of manufacturing the company was feeding small lumps of chocolate into a fan that broke it up and blew it through a galvanized pipe into the cyclone dust collecter in the dust room. This is the operation that is supposed to have caused the explosion.

As a result of an investigation it was concluded that the ignition of the chocolate dust was brought about by a spark made by a loose blade in one of the fans striking against the casing, by a piece of metal being blown through the metal pipe and striking against the side of it, or by a piece of metal being hit by a blade of the fan while passing through the blower.

CORK DUST.

Philadelphia, Pa. An accumulation of cork dust on some pipes in a drier caused a flame which ignited the dust and resulted in an explosion in a plant in Philadelphia on August 13, 1913. The plant was partially destroyed and a loss of nearly $6000 was incurred.

A second explosion occurred in the same mill on March 27, 1914, caused by the ignition of the dust by sparks from foreign material passing through the grinding rolls. This was not as extensive an explosion as the former one, and resulted in only a small loss.

Baltimore, Md. An explosion occurred in a cork works in Baltimore, Md., on June 29, 1917. Overheated cork from an attrition mill was carried through the conveyor into a bin where it ignited the dust, causing the explosion.

Nicetown, Pa. Seven workmen were seriously injured and a large oilcloth and linoleum plant in Nicetown, Philadelphia, Pa., was nearly destroyed on February 27, 1918, as the result of a fire and dust explosion. The fire, of unknown origin, was carried through spouts to bolting reels on the fourth floor and then through other spouts to screw conveyors where it was discovered. It spread rapidly but was under control when water was turned on a pile of powdered cork in one portion of the plant. As soon as the water struck the cork dust, a cloud was thrown into suspension and a serious explosion resulted.

Philadelphia, Pa. A small fire and explosion occurred in a cork factory in Philadelphia, Pa., Feb. 1, 1919. Friction from a broken belt as it wound around the shaft caused the fire which exploded the dust. The force of the explosion raised the roof.

COTTON DUST.

Woonsocket, R. I. A slight explosion or puff occurred in the gauze room of a cotton mill in Woonsocket, R. I., on October 24, 1913, blowing the door open and sending a blast of fire out over two men who had been feeding the picker. Both were fatally burned. A batch of mixed black-dyed wool, 25 per cent cotton waste and 75 per cent Egyptian cotton comber waste, was being passed through the mixing picker into the gauze room at the time of the explosion. The damage was slight, being confined almost entirely to the stock in the gauze room. The cause of the explosion was not determined, but the dust may have been ignited by fire started in the picker.

Nashua, N. H. A small fire in the west end of the lint room of a cotton mill in Nashua, N. H., on January 19, 1914, was immediately followed by a dust explosion which vented itself into the east end of the lint room by blowing open a latched fire door opening into the basement. It blew out half a sash in the basement and passed up a stairway to the motor room in the first story where a fixed sash and lights of glass in the further end of the room were blown out. Men who were cleaning out the lint in the west room nearest the discharge of the collector, as was customary every few days, discovered fire in one of the baskets used for removing the lint.

Cleveland, Ohio. On October 7, 1916, an explosion of cotton dust occurred in a mill in Cleveland, Ohio, in which cotton and wool fabrics were reclaimed. In the process considerable dust is produced which is disposed of by means of a fan blowing it into a separator. The explosion, which was not serious, originated in the interior of the separator, and was caused by sparks struck by foreign material passing through the fan. No one was injured and the plant was only slightly damaged.

FERTILIZER PLANT.

Chicago, Ill. The loss from an explosion which occurred in a fertilizer plant at Chicago, Illinois, on January 4, 1916, was small because of the fact that no fire followed.

The chief process carried on at this plant was the pulverizing of various grades of dried tankage of different chemical analyses, and the blending of them into a finished fertilizer. The handling of the kiln-dried tankage which contained only such moisture as it absorbed from the atmosphere in being shoveled from one pile to another on the open floor or in being wheeled in small dump carts, caused the air to be so laden with dust at all times that the workmen were compelled to wear protectors over their faces. The greater portion of this dust was from the pulverizers or mechanical shakers which were entirely exposed.

It was impossible to locate exactly the seat of the explosion or to assign a cause, although it is believed that a spark struck by an iron bucket in one of the elevator trunks, ignited the dust there.

POWDERED MILK.

ANOKA, MINN. A fire and two explosions occurred in a powdered milk factory at Anoka, Minn., on July 10, 1918. The plant had been shut down but a few moments and it was supposed that everything was in good order. Suddenly a small explosion occurred. This was followed by another and more violent explosion, and by fire which destroyed the plant, causing a loss of $30,000. The origin of the explosion has not been determined, but there is a possibility of its having started from milk dust in the drying chamber.

PHONOGRAPH RECORD DUST.

BRIDGEPORT, CONN. Explosions and fires occurred in a graphophone plant in Bridgeport, Conn., on March 27, 1917, and March 6, 1918, in which one man was badly burned. The loss was small. Both of these explosions were caused by foreign material in the grinders. The release vents worked satisfactorily in the first case and in the second they so modified the effects that but one of the machines was damaged. On Jan. 8, 1919, in another graphophone factory in the same city an explosion in the grinding machine resulted in slight loss.

WEST ORANGE, N. J. It was thought that pieces of metal in one of the Fuller mills used for grinding phonograph records caused the explosion and flames which occurred in a phonograph works in West Orange, N. J., May 11, 1917. The loss was $35,000.

RUBBER FACTORY.

DANVERSPORT, MASS. On January 6, 1914,[1] an explosion occurred in the grinding mill of a rubber reclaiming factory in Massachusetts. The building was of frame construction, open on one side. The steel rollers were located about midway between the top and bottom of the mill. The fine dust created by the process of grinding ascended to the hood of the mill where a blower system carried it through metal ducts to a frame bin nearby. The ground rubber dropped to the bottom of the mill.

The fire was said to have started when a spark from a piece of steel in the rubber stock ignited the fine dust in the hood of the mill. A small dust explosion followed and the frame mill, with a considerable quantity of ground rubber in the bottom, took fire.

MUSKEGON, MICH. On August 18, 1920, 8 men lost their lives and one was seriously injured in an explosion of rubber dust in a rubber recovery plant in Muskegon, Mich. Property was damaged to the extent of about $25,000. In the process of recovery, scrap rubber was first broken up into small pieces and then pressed between steam-heated rolls before being ground. Large quantities of fine dust were produced. The explosion is supposed to have started in this grinding, but all the evidence which would prove the exact point of origin was destroyed. It is presumed that the explosion started either from foreign material in the grinding machines or possibly from an ignition of the dust by a lighted match or the breaking of an electric light bulb.

SHODDY MILL.

CLEVELAND, OHIO. An explosion occurred in a shoddy mill in Cleveland, Ohio, February 27, 1910, in which three persons were injured. The cause assigned was that sparks were struck by a workman's hoe on the brick in the dust vault while it was being cleaned. The vault and the cyclone collector on it were completely destroyed.

CLEVELAND, OHIO. An explosion occurred in the cyclone collector of a woolen shoddy mill in Cleveland, Ohio, March 18, 1910. It was followed by a fire which, passing through the vent pipes, caused a second explosion.

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[1] From N. F. P. A. Fire Record Data.

SOAP FACTORY.

Providence, R. I. An explosion of soapine dust occurred in a soap works in Providence, R. I., on August 4, 1890,[1] in which 2 men were killed, 9 were injured, and the property was badly damaged. The company was engaged in the manufacture of high-grade soap and soapine, which was composed of a good quality of soap mixed with either soda or soda crystals. The mixture was dried, ground, and put into packages for domestic purposes. For years the mixture had been ground in a small room lighted by an open gas burner, which was exposed to the clouds of dust that arose from the open grinding mills. It was found that during the grinding operations the dust that came from the grinding mills in such quantity at certain times as to extinguish the gas jet was nearly pure soap, as fine as flour, and very dry. With testing equipment similar to that used by Professor L. W. Peck following the Minneapolis explosion,[2] Professor S. F. Peckham found that graham flour, wheat flour, starch, powdered sugar, rice flour, coal dust, planing mill dust, furniture dust, powdered asphaltum and all similar substances could be exploded with the greatest ease. When the conditions under which soap dust would explode were determined, it was shown that greater explosive force and more intense heat can be produced from the explosion of soap dust than from any manufactured wheat product. It was therefore concluded that the explosion was produced by the ignition of the mixture of soap dust and air in the proper proportions, from the open gas jet.

SPICE AND SHELLAC FACTORY.

Newark, N. J. On January 29, 1915, an explosion of shellac dust occurred in a New Jersey spice and shellac grinding factory. The products were being ground in an attrition mill. The cause of the explosion was attributed to the fact that metal or foreign material entered the grinding machine and produced sparks that ignited the dust cloud which was present. The fire, starting from a mild explosion in the attrition mill, was followed by a severe flash of fire. Shellac is a resinous gum and is very inflammable in a finely powdered form.

SPICE DUST.

Cincinnati, Ohio. During the progress of a fire in a tea and spice mill in Cincinnati, Ohio, on January 17, 1920, there was an explosion which blew out a portion of the walls of the building. Four firemen were killed and 13 other persons were injured. The explosion is supposed to have occurred when a falling floor threw into suspension a quantity of ground spices which was in open containers. The total loss was estimated at $150,000.

SULPHUR DUST.

Toronto, Canada. An explosion occurred in April, 1911, in the elevator of a chemical plant in Toronto, Canada, which was used to lift powdered sulphur. The legs and head of the elevator were made of wood, the other parts of metal. The explosion was thought to have been caused by frictional electricity. It blew off the cover boards and leg and set fire to the sulphur. Since the elevator has been lined with sheet metal and carefully grounded no ignitions or explosions have been experienced. The loss was about $500.

New York City. On November 25, 1912, an explosion of sulphur dust occurred in a grain elevator in New York, used for the storage of raw sulphur. The sulphur was unloaded into the hoppers at the ends of the elevator, raised by the conveyors and dumped into the top of the bins in much the same way as the grain was handled in former units. At the time of the explosion and fire two bins only were used, containing about 175 tons of sulphur.

The explosion lifted the roof of the elevator partly off. It settled back in position and for a few seconds conditions seemed normal. Then the elevator

[1] Chemical Engineer, May, 1908, vol. 7, No. 5, pp. 195-6.
[2] Chemical Engineer, March, 1908, vol. 7, No. 3.

was enveloped in a mass of flames. When the conveyor machinery was in operation there was considerable dust in the air, and the interior of the elevator was probably covered with it. The evidence shows that the conveyor system was in operation but became deranged in some way, causing a large quantity of sulphur to fall to the second floor just prior to the first explosion. It is probable that the sulphur dust was ignited by the striking of sparks by the iron elevator buckets or by some other parts connected with the operation of the machinery. Fifteen persons were injured, ten by burns and the other five by flying or falling debris at the time of the explosion.

Boston, Mass. Two men were slightly burned but the loss was small in an explosion which occurred in a rubber factory in Boston, Mass., on Feb. 6, 1913. The men were pouring a barrel of flowers of sulphur over a sieve which was enclosed in a wooden box, when a flash and slight explosion occurred. The explosion is supposed to have been caused by the ignition of the sulphur dust by static electricity as the weather conditions, cold and dry, were favorable for its generation.

Hartford, Conn. Fire, followed by an explosion, broke out in the sulphur conveyor and sifter on the top floor of a rubber works in Hartford, Conn., on Feb. 23, 1914. Two wooden covers were blown from the sides of the sifter. Similar fires followed by less violent explosions had occurred in the same machines two weeks previously. It is believed that they were caused by sparks of static electricity or mechanical sparks in the sifter or conveyor.

Toledo, Ohio. A dust explosion occurred December 16, 1921, in an insecticide plant manufacturing lime-sulphur. It was confined to the filter bag dust collector and the duct connecting the dust collector and the exhaust fan, also the duct from the exhaust fan to the ventilator on the roof of the building. This explosion was caused by a discharge of static electricity from the filter bag to the shell or hopper of the collector. An investigation after this explosion showed, under certain conditions, a difference of potential of 30,000 volts on the filter bags. Proper grounding removed this hazard.

Louisville, Ky. Six men were seriously injured in a sulphur dust explosion which occurred March 12, 1922, in Louisville, Ky. At the time of the explosion, sulphur was being separated and collected in the filter bag type and cyclone dust collectors. It is believed that this explosion was caused by one end of the screw conveyor underneath the filter type dust collector becoming loose and rubbing on the jacket, causing sparks which ignited the sulphur dust. Considerable damage was done to the plant.

BARK DUST.

Michigan. Explosion of bark in a tannery and extract company in Michigan, on August 29, 1916, resulted in a loss of $800,000. The friction created in grinding the bark ignited the dust particles which were of such a nature that the fire spread almost instantaneously throughout the building.

EXPLOSIONS IN EUROPEAN COUNTRIES.[1]

The earliest work done in the attempt to determine the causes and develop means of prevention of dust explosions was carried out in European countries, more particularly as a result of explosions in coal mines. However, the factories of European countries in general and more particularly those of England and France have sustained losses in several severe dust explosions. As has been noted in the first chapter, investigations have been made as a result of these explosions to ascertain the hazards of dusts in various industries. Explosions have not occurred in the other countries, largely because of the fact that they are not doing much manufacturing and most of the plants are of limited capacity. Many small

[1] The authors are indebted to the Consular Service of the State Department of the United States Government for much of the material regarding explosions in European countries.

explosions have occurred in European countries, but these will not be included in the brief resumé which follows.

BRITISH ISLES.

GLASGOW, SCOTLAND. As early as July 9, 1872[1], a violent explosion occurred at the Tradeston Flour Mills, near Glasgow, Scotland, in which 18 persons were killed, 16 injured, and the property damaged to the extent of about $350,000. The explosion was investigated by Messrs. Rankin and MacAdam, who gave out the following statement: "The origin of the explosion was traced to the striking of fire by a pair of millstones through the stopping of the feed, and the consequent friction of their bare surfaces against each other. The flame thus produced was quickly communicated to the mixture of dust and air filling the conduits connected with the exhaust box; this being the common receptacle into which the mixture of dust and air is drawn by an exhaust fan through the conduit communicating with the several mills. From the exhaust box, a portion of the suspended flour dust passed in the Tradeston, as in other flour mills, to another room called the stive room where a further quantity of the flour would deposit."

A surviving workman stated he carried a lamp, so it may be concluded that open lights were used without being regarded as dangerous.

MACCLESFIELD AND ROCHDALE, ENGLAND. On September 14, 1881[1], an explosion occurred at the mill of Fitton & Son, Macclesfield, Cheshire. The report of the investigation states that the cause was traced to the use of very dry grain and the accidental stoppage of the feed. It is also reported that in February, 1882, an explosion occurred at Rochdale, in the exhaust (dust) room through the stones striking fire. In the fire following, the plant was damaged to the extent of about $130,000.

MAGNESIUM PULVERIZING PLANT.

GREAT BRITAIN. An unusual catastrophe was reported in 1911, in a mill where one of the processes carried on was the grinding of magnesium. After a visit by the inspector, notice was served requiring the installation of an exhaust system to prevent the diffusion of the dust. On a subsequent visit the occupant of the mill stated he had not complied, as he preferred to give up the process. For some reason, however, he did, in fact, grind the substance again and during a heavy thunderstorm the dust was ignited by lightning. During the progress of the fire, there were repeated explosions of such volume that it was assumed the boilers had burst. It is stated that the magnesium dust instantly diffused and fired throughout the factory, so that the workers hardly had time to escape, and also that the water thrown on the magnesium made matters worse.

PROVENDER OR FEED MILL.

GLASGOW, SCOTLAND. On November 10, 1911[2], an explosion occurred in the provender or feed mill of William Primrose & Sons, Ltd., Glasgow, in which five persons (including three children) were killed and eight persons were injured. Investigations by a government inspector led to the conclusion that the direct cause of the explosion was the dust which had accumulated on an overhead beam becoming dislodged and falling upon the open flame of a Bunsen burner. Peas, beans, and wheat were being ground at this mill, and at the time of the explosion all the millstones except those used for grinding wheat were running. The explosion occurred about 6:30 in the evening when work was being carried on by artificial light. The plant was lighted by naked gas jets and two of these were

[1] Supp. J. Soc. Chem. Ind. Jan. 31, 1906, vol. 25, No. 2, p. 54. "Flour Mill Explosions and Dangerous Dusts." Watson Smith.

[2] Reports of H. M. Inspectors of Factories on the circumstances attending explosions which occurred at the works of Messrs. William Primrose & Sons, Limited, Centre Street, Glasgow, on November 10, 1911, and at the works of Messrs. J. Bibby & Sons, Formby Street, Liverpool, on November 24, 1911, published in 1912.

located on the first floor where the explosion originated. The cause of the explosion, however, was assigned by the inspector to a portable gas burner, used by the millers for dressing the millstones, being placed in a spot where dust could have fallen on it.

SEED CRUSHING MILL.

LIVERPOOL, ENGLAND. The most serious dust explosion reported from England occurred in the plant of J. Bibby & Sons, Formby Street, Liverpool, on November 24, 1911[1]. Thirty-nine persons lost their lives and 101 others were injured. In the investigation conducted by a government inspector it was concluded that the explosion originated in the basement of the plant about 10 feet below the street level, where 6 large disintegrators were grinding oil cake, locust beans and other materials. The inspector reached the following conclusion as to the cause of this disaster: "The explosion was, in my opinion, a result of the ignition of a dense cloud of dust produced by the breaking of the driving belt of the 'street end dressing machine' disintegrator in No. 1 floor of block 18 (basement). The disintegrator belts were 6 inches wide, they ran at a speed of 5000 feet per minute, and the workmen say that when they broke they caused a cloud of dust 'like a fog' for a minute or two, due to the dislodging of accumulations of dust on the girders, machinery and plant.

"The definite source of the dust was not determined, but in experimental work conducted with samples of dust collected from wall ledges and overhead pipes it was found that an explosion of a dense cloud of such dust could be caused by (1) the ignition of a match, (2) contact with a naked gas flame, (3) the flash caused by the fusing of an electric wire, (4) sparks produced by breaking circuit of an electro-magnet wire, or to the bursting of the uncovered fuse on the temporary switchboard, at the very moment when a dense cloud was formed by the breaking of the disintegrator belt."

ABERDEEN, SCOTLAND. In December, 1911, a slight dust explosion occurred in a large dust-collecting house of a cattle feed works at Aberdeen, Scotland, in which oat husks were being ground. In this case only one man was injured. A large window, originally fixed in the dust house to take the force of any explosion, probably saved the building from being wrecked and automatic sprinklers prevented the spread of fire from the dust house to the mill. The millstones were faced with emery and set very close to each other. The explosion was considered to be a result of ignition of the dust in the dust house by sparks from a piece of metal between the stones. No naked lights were used on the premises.

DEXTRINE PLANT.

MANCHESTER, ENGLAND. An explosion in which eight men were injured, three of whom died subsequently, occurred at the works of Laing, Son & Co., Holt Town, Manchester, on March 11, 1913[2]. A previous explosion occurred at the plant on March 21, 1911, the circumstances surrounding each explosion appearing somewhat similar. In the first explosion, three men were killed and five were seriously injured, and extensive damage was done to property.

The company manufactured dextrine (British gum). Starch, flour, and small quantities of hydrochloric and nitric acids were the only substances used. The investigations conducted by the inspectors indicate that the explosions in both cases originated in the same manner, and it was decided that an ignition of dust was produced inside the casing of the fan which was forcing the hot air to the drying stoves located in the end of the plant.

The inspector states that there were "two means of ignition in the engine house, viz.: (1) an open gas-jet, 3½ feet behind the center line of the engine crank

[1] Reports by H. M. Inspectors of Factories on the circumstances attending explosions which occurred at the works of Messrs. William Primrose & Sons, Limited, Centre Street, Glasgow, on November 10, 1911, and at the works of Messrs. J. Bibby & Sons, Formby Street, Liverpool, on November 24, 1911, published 1912.

[2] Report on the circumstances attending an explosion which occurred at the works of Messrs. J. Laing, Son & Co., Holt Town, Manchester, on March 11, 1913, by John Jackson, H. M. Superintending Inspector of Factories.

shaft and about two feet below, but on one side of the beams supporting the fan, and (2) the ignition tube of the engine itself. It was stated in evidence at the inquest that the gas engine had been 'knocking' a short time before the explosion occurred; this 'knocking' or back firing would shake the engine house and tend to dislodge any dust accumulations. It was thought that ignition of the dust in the fan casing occurred as follows: Some accumulation of dust was dislodged, probably from the beam supporting the fan and, falling into the gas light below, was ignited; the flame was then drawn into the fan casing either through the openings in that duct which was badly fitted at its junction with the casing of the fan." Continuing, the inspector concludes: "I have therefore come to the conclusion that the initial cause of the explosion was a fire in the fan casing, set up in the manner described. This flame was driven along the hot-air duct setting up an explosion wave within the duct, which finally exploded the contents of the stoves on the south side of the front cellar, either by firing directly the dust at the bottom of the stoves or by causing the evolution of inflammable gases (by destructive distillation of the dust on the trays and racks) which were fired by the flame and immediately propagated an inflammation." A series of seven samples of material in process of manufacture (including one of the flour in the stoves) as well as dust from the grinders was collected and tested by Dr. R. V. Wheeler. and it was found that "all these samples are obviously of a highly inflammable nature and, when present as a cloud in air, are capable of propagating flame rapidly."

As a result of this investigation the two following recommendations were made:

1. Gas engines, oil engines, gas producer plants and steam boilers should not be placed in rooms or parts of the premises which communicate directly with rooms where inflammable dusts are liable to be generated.

2. Exhaust and plenum fans used in connection with places where inflammable dusts are liable to be generated should be kept thoroughly clean and free from accumulations of dust and oil to prevent the possibility of a hot bearing firing such an accumulation, and so causing an explosion.

SHODDY DUST.

Ossett, York, England. Two explosions of shoddy dust are reported to have occurred in a rag carbonizing plant at Ossett, June 2, 1913.

In the first explosion which occurred in one of the carbonizing machines when the doors were opened while it was revolving, 3 men were severely burned. The ignition of the dust cloud in the machine was probably due to friction of a match in a pocket. The second explosion in which one man was slightly burned, occurred in a rag shaker. In this case the attendant had neglected to remove an accumulation of dust which was below the shaker.

MALT DUST.

Selford, England. On June 19, 1913, one man was slightly burned when malt dust exploded in a brewery at Selford. After passing through a mill the crushed malt dropped into a hopper or bin. In order to examine this hopper a portable gas jet was introduced and the ignition of dust occurred.

CORK DUST.

Lancaster, England. Three men were slightly burned in an explosion of cork dust at a linoleum factory in Lancaster, June 24, 1913. The cork used in the manufacturing process was ground in a mill and then passed into an elevator. For some reason a small ball of cork formed within the grinding mill and finally burst into flame. The explosion occurred when this flame reached the elevator where dust was in suspension.

COAL DUST.

Manchester, England. An explosion of coal dust occurred at a plant manufacturing oil cake in Manchester, June 24, 1913. During the shoveling of pul-

verized coal from a duct leading to the furnace of the boiler considerable dust was thrown into suspension. The cover forming the top of the duct was cracked and a spark or hot cinder from the boiler flue is supposed to have entered the duct and ignited the dust cloud. Two men were burned in this explosion.

MITCHELDEAN, ENGLAND. On September 8, 1913, an explosion of coal dust occurred at a cement plant at Mitcheldean. Coal was being pulverized for use at the plant and the explosion occurred when fine dust was ignited by sparks from a rotary kiln. One man was severely burned in this explosion.

DISTILLERY MEAL.

LIVERPOOOL, ENGLAND. An explosion of distillery meal occurred during the manufacture of oil cake at a plant in Liverpool, September 5, 1913. Two men were burned when dust in one of the elevators was ignited, either by friction of the elevator buckets against the side casing, or by a spark produced when the buckets struck a stone or other foreign material entering the elevator with the meal.

COPAL GUM.

WANDSWORTH, ENGLAND. An explosion occurred November 21, 1913, at a plant in Wandsworth where gramophone records were being manufactured. Copal gum was used in the process and the material was ground in a disintegrator. The original ignition of dust occurred in this machine and is supposed to have been caused by a piece of stone, metal or other foreign material entering the machine. The flames propagated from the machine and an explosion occurred when they reached the dust-collecting balloon attached to the machine. One man was severely burned and 3 slightly injured in this explosion.

FRANCE.

There have been dust explosions in various factories and milling plants in France for many years. Some of these were violent in nature and caused the loss of several lives and considerable damage to property, while others were not exceptionally destructive. These dust explosions and fires occurred in flour mills, confectionery factories, bakeries, aluminum factories and similar plants where dust was produced during the operating process.

A number of the explosions and fires were caused by the introduction of open flames, especially lanterns, into dusty atmospheres. The explosions and fires in flour mills were assigned to several causes, chief of which were the following: (1) Heated bearing in rye cleaning room; (2) bolting room approached with ordinary lantern; (3) winnowing machine became overheated; (4) workmen cleaning dust room with open flame lamp; (5) dust room lighted with lantern having a broken globe; (6) lower part of elevator being cleaned and a sudden fall of dust ignited by naked candle used for light; and (7) use of open gas jets. Several explosions in aluminum powder factories have been reported in which some of the workmen were killed and others injured and also a number of explosions in bakeries as a result of ignition of dust by gas jets.

PAPER MILL.

TOURCOING, FRANCE. An explosion of paper dust occurred in a paper cylinder factory at Tourcoing, France, on May 31, 1913[1]. Two workmen lost their lives. Paper tubes, such as are used in cotton mills and weaving mills were manufactured at this plant. In order to facilitate the gluing of the cylinders the borders of the thick papers were sharpened by grinding. The dust produced in this process was carried from the machine by suction to a brick building which served as a dust chamber.

On the afternoon of the explosion the usual weekly cleaning of the dust chamber was being done, the workmen using ordinary lanterns filled with rape-seed

[1] Rauch und Staub, Feb. 1914. Jahrb. 4, No. 5.

oil. After about 3 hours the work was interrupted for a short time. One workman returned and entered the chamber with his lantern while another climbed upon the roof to remove the dust from the chimney filters. Suddenly there was a violent explosion which killed the two workmen and wrecked the work chamber. The lantern used by the worker was found in the chamber afterwards with two panes broken. There seems no other possible cause for this explosion than the ignition of the dust by the flame of the lantern.

In comparative tests of paper dust and coal dust at the Lievin, France, experiment station, it was found that the inflammability of the paper dust is somewhat smaller, but of the same order of magnitude as that of pure Lievin coal (30 per cent of volatile matter and 7 to 8 per cent of ash screened through a 200-mesh sieve).

CEREAL MILL.

Corbeil, France. In 1892, an explosion occurred in a cereal mill in Corbeil, France, resulting in the death of four workmen[1]. The explosion happened during the cleaning of a dust chamber, wherein was collected the dust arising during the cleaning of cereals. An eye witness (workman) described the origin of the explosion as follows: "All of a sudden I saw a few little flames issuing from the lantern suspended from the wall and playing lightly over the wall. The little flames gradually increased in extent. I tried to extinguish the fire which caught the dust adhering to the wall, but I could not master it; in an instant the wall was all covered with flames, then the ceiling, and then the explosion occurred."

CONFECTIONERY FACTORY.

Angers, France. An explosion occurred in the drying room of a confectionery factory at Angers on July 6, 1904[2], in which 1 person was killed and 3 injured seriously. It is stated that a workman dropped some "plaquettes" of gum rolled in starch on a heating pipe of a red-hot stove, which caused an ignition of the starch dust and an explosion followed.

SUGAR REFINERY.

Paris, France. An explosion is reported as occurring in a sugar refinery in Paris on May 22, 1908[2], in which 3 persons were killed and 49 injured. The explosion seems to have occurred in the bolting room situated on the ground floor of a building whose upper floors were devoted to crushing rooms. The possible causes suggested were sparks from uncovered (exposed) dynamo brushes in the bolting room, or a smoker's carelessness.

GARANCINE FACTORY.

Sorgues (Vaucluse), France. A violent explosion occurred in a garancine factory in Sorgues (Vaucluse) November 13, 1878[3], in which six workmen were killed. In order to get a product of desired quality the garancine, obtained by the action of sulphuric acid on garance (madder root) had been pulverized and the different lots had been mixed with a shovel in a special room, which became filled with very fine and explosive dust. It was forbidden to enter with fire, and when artificial light was needed the lanterns were left in a nearby chamber communicating with the mixing room.

The first shift had finished at about 5:45 in the morning and a second one came to take its place in the mixing room, the first shift leaving the lantern near the door. On proceeding with the mixing a workman with a shovelful of garancine came near the lantern, breaking a pane of glass. A violent explosion occurred. The workmen tried to escape into an adjoining room, closed only by a curtain, but the curtain took fire and they themselves were covered with burning dust and

[1] Rauch und Straub, Feb. 1914. Jahrb. 4, No. 5.

[2] Rapports du Service de l'Inspecteur du Travail (Reports of Labor Inspector Service). Taken from abstract of Dust Explosions furnished by the Labor Inspector Service to American Consul Burnell, Rouen, France, Sept. 7, 1915.

[3] Rapport de M. l'ingénieur des mines Lacchat, Communiqué par M. Villot à une réunion de la Société. (Comptes-rendus mensuels de la Société de l'Industrie Minérale. 1878, p. 245. Consular Report, Consul Burnell, Rouen, France, Sept. 7. 1915.)

lost their lives. The report of the explosion states further: "Under the circumstances no inflammable gas could serve as a medium of inflammation and the comparison of the dust and gas with the powder and percussion cap of a cartridge could not be admitted. As a consequence it must be conceded that in this case the thinness and abundance of dust were sufficient with the contact of the flame to cause the explosion. It is to be observed that garancine drying rooms are very large and have a capacity of some hundreds of cubic meters. It may be admitted that the dust of garancine dried in a drying room, all other circumstances being equal, is more inflammable than that of coal."

OTHER EUROPEAN COUNTRIES.

Reports of explosions received from other European countries are not as complete as those from France and England. The most important explosion reported from Germany from dust in a dextrine factory, probably was caused by a short circuit. Others were several aluminum powder factory explosions; some explosions in the Bremen district, presumed to have been caused by hot bearings; and an explosion of dust from cleaning machinery in a large mill in the Rhine district. It is reported that in recent years a mill at Bakes Csaba, Hungary, was destroyed by fire, the origin of which is attributed to a "dust explosion caused by friction of the iron parts of the machinery." Reports from Switzerland state that in 1898 the first flour explosion for a decade took place. A machinist left a lighted candle and went up to the top floor, through the cracks of which flour and dust fell and became distributed through the air of the room. The result was a sudden explosion in which the man was seriously injured. In 1902 a dust explosion took place when a lighted lantern was put into a flour bin. The bin was destroyed, part of the roof was blown off and the workman was seriously burned.

Reports state that prior to 1878 an explosion occurred in a mill in Budapest, Hungary. The workmen were mixing some fine varieties of flour (the door of the mixing room being left open) when the thick cloud of dust became ignited from an open light. A similar explosion is reported as having taken place at Friedeck.

It is reported that a mill in the vicinity of Palermo, Italy, experienced an explosion about 1895. It is said to have been caused by the "lighter dust coming in contact with an overheated valve." Explosions of cork dust are reported from the cork plants at Seville, Spain. In the Netherlands a Safety Decree was issued June 27, 1913, including rules for the prevention of dust explosions, prohibiting the use of open flames and making special provisions for electrical installations.

Complete details have not been received, but available information is to the effect that two explosions occurred in sugar factories in the Rhenish Palatinate, one in February, 1916, the other in May, 1917. In these explosions 7 workmen were killed, several were more or less seriously injured, and the plants were partially destroyed. In an investigation which followed no definite causes for the explosions were established.

In the past ten years, 1911-1921, there have occurred in Austria 10 noteworthy dust explosions in industrial enterprises. In one of these 3 workmen were killed and in each of three others 1 workman was injured. In the other 6 explosions no material damage was done. In regard to the details of the explosions mentioned, the Austrian Ministry for Social Welfare (Bureau of Supervision of Industrial Enterprises), has given the following information:

A coal dust explosion took place in the boiler-room of a cement factory during the sweeping of the room. One workman was severely injured.

As a result of the explosive ignition of flax dust in the kiln of a flax fiber-weaving mill 3 workmen were burned to death. In order to prevent such accidents in the future, the board of inspectors ordered that the flax kiln should not be left unwatched until the main pipe of the heating apparatus should have completely cooled off.

A fire explosion caused by the spontaneous ignition of aluminum dust took place in a factory making bronze coloring material, white metal articles and

Christmas tree ornaments. The whole factory was destroyed. In this case the damage was confined to property.

Four dust explosions occurred in textile mills. In two cases (factories for woven goods) sparks from unprotected electric motors set fire to the raw woolen shreds. The motors were accordingly removed from the rooms. In another woolen factory an explosion of the dust collected in a fireproof drying and carbonizing room occurred when the room was opened. In the fourth textile mill the coal dust collected in a cleaning machine for carbonized rags caught fire and exploded during the operation of the machine. No workmen were injured in any of these explosions.

In the case of a flour mill a violent explosion occurred in the course of cleaning out the supply chests of a flour-mixing machine. In addition to considerable material damage, one workman was severely burned. In all probability this explosion was caused by the fact that, contrary to regulations, the supply room was lighted with an open-flame lamp instead of with a closed safety lamp.

Sugar refineries were the scene of two sugar dust explosions, in one of which a workman was badly injured. These explosions were ascribed to the formation of sparks in the transmitting channels owing to a slight mixture of particles of iron. To prevent such accidents in the future, measures have been taken to prevent any particles of iron from penetrating into the parts of the mill where sugar dust is liable to collect.

Czegled, Hungary. The only explosion which has occurred in Hungary in recent years took place in a flour mill when an electric bulb broke in a flour bin.

Kuopio, Finland. According to information from the American consul at Helsingfors, Finland, the only dust explosion which has occurred in that country was in the grain elevator of a five-story wooden warehouse. It was thought to have been caused by friction between some belting and neighboring wooden parts, producing sparks which set the dust afire. The fire developed rapidly in the warehouse, which was filled with dust, and completely destroyed the building.

TABLE XXV.

PLANT DUST EXPLOSIONS IN THE UNITED STATES AND CANADA.

Location.	Date.	Supposed cause.	Number killed.	Number injured.	Damage.
Flour Mills.					
Milwaukee, Wis.	—— 1860	Lantern	—	1	Partial
Mascoutah, Ill.	—— 1864	Lamp	—	1	Complete
Jordan, Minn.	—— 1875	Unknown	—	—	Complete
Evansville, Ind.	April 2, 1875	Lamp	—	—	Complete
Rochester, N. Y.	—— 1877	Open lantern	—	—	Partial
Baldwin, Wis.	—— 1878	Open lantern	—	1	Partial
Des Moines, Iowa	—— 1878	Unknown	—	—	Partial
Minneapolis, Minn.	May 2, 1878	Sparks from grinding stones.	18	—	$800,000
St. Louis, Mo.	Aug. —, 1881	Lightning	—	—	Complete
———, Minn.	May 19, 1882	Lantern	—	2	Slight
Chicago, Ill.	—— 1885	Lantern	—	1	Slight
Council Bluffs, Iowa	Oct. 17, 1887	Open lanterns	—	—	Partial
Cleveland, Ohio	Sept. —, 1888	Lantern	2	12	Complete
Litchfield, Ill.	Mar. 21, 1893	Ignition of dust by flames from fire.	1	—	$500,000
Boone, Iowa	Sept. 18, 1899	Lantern	—	Several	Partial
Arkansas City, Kans.	June 17, 1903	Unknown	1	1	$150,000
Niagara Falls, N. Y.	June 21, 1906	Ignition of dust in bin	—	—	Partial
New York, N. Y.	July 6, 1909	Spark in screw conveyor	—	—	Partial
Portland, Ore.	Sept. 16, 1909	Sparks from nail in grinding rolls.	—	—	$300,000
Elkhart, Ind.	Oct. 21, 1909	Unknown	—	—	$50,000
Arendtsville, Pa.	Sept. 13, 1913	Foreign material in scourer.	—	—	$16,000
Leavenworth, Kans.	Nov. 1, 1913	Sparks in feed grinding machine.	—	—	Slight
Long Island City, N. Y. (Macaroni works).	Nov. 21, 1913	Sparks in conveyor	—	—	Complete
Beatrice, Neb.	Sept. 22, 1914	Match	—	1	Partial
Ypsilanti, Mich.	Dec. 4, 1914	Unknown	—	—	$25,000
Newark, Del.	Oct. 5, 1916	Unknown	—	—	Nearly comp.
American Falls, Idaho	May —, 1917	Unknown	—	—	$60,000
Benton, Pa.	Feb. 21, 1918	Unknown	—	2	$45,000
Fort Valley, Ga.	Mar. —, 1918	Lighted pipe	—	—	Very limited
New Prague, Minn.	April 7, 1918	Sparks in rolls	—	—	Partial
Cheney, Wash.	April 14, 1918	Open torch	—	—	$300,000
Winterville, Ga.	Mar. 10, 1919	Unknown	—	—	Complete
Memphis, Tenn.	Oct. 13, 1919	Unknown	—	—	Partial
Boissevain, Man., Canada.	Dec. 6, 1919	Match	—	—	$6,000
Denver, Colo.	Jan. 20, 1920	Sparks in exhaust fan	—	—	$100,000
Kansas City, Mo.	Mar. 15, 1922	Spark in rolls	—	—	$5,000
Elevators					
Toledo, Ohio	Sept. 20, 1898	Lantern	10	5	Complete
Richford, Vt.	Oct. 7, 1908	Not determined	17	3	$139,000
Minneapolis, Minn.	Sept. 16, 1909	Unknown	—	—	Partial
Grand Rapids, Mich.	Aug. 11, 1910	Unknown	—	—	$78,000
Chicago, Ill.	Feb. 5, 1912	Unknown	—	—	$500,000
Chicago, Ill.	Aug. 16, 1912	Unknown	—	—	Partial
Philadelphia, Pa.	Apr. 25, June 30, July 23, 1913	Flames from boiler in dust feed pipe.	—	—	Slight
Akron, Ohio	Dec. 2, 1913	Broken electric light	—	—	Slight
Chicago, Ill.	Feb. 7, 1914	Unknown	—	—	Complete
Galveston, Tex.	Mar. 30, 1914	Static spark	—	—	$6,500
Minneapolis, Minn.	April 10, 1915	Unknown	—	—	$20,000
Portsmouth, N. H.	May 14, 1915	Unknown	—	—	$555
Weehawken, N. J.	July 15, 1915	Spark from foreign material.	—	—	$50,000
New Orleans, La.	Dec. 14, 1915	Friction in leg	—	—	Partial
El Reno, Okla.	Dec. 21, 1915	Choke in elevator leg	—	—	$2,500
Peoria, Ill.	Mar. 6, 1916	Choke in elevator leg	—	—	$600,000
Fort Worth, Tex.	Mar. 9, 1916	Foreign material in rolls	—	—	Partial
Baltimore, Md.	June 13, 1916	Choke in elevator leg	7	22	$1,500,000
Minneapolis, Minn.	Feb. 15, 1917	Unknown	—	—	Partial
Lemon, S. D.	April 2, 1917	Unknown	—	—	$12,000
Minneapolis, Minn.	June 16, 1917	Unknown	—	—	$200,000
Brooklyn, N. Y.	Oct. 13, 1917	Rubbing of belt against side of elevator leg.	—	—	$1,750,000
Fife, Mont.	Dec. —, 1917	Striking bent cup	—	—	$30,000
Beach Grove, Ind.	June 14, 1918	Unknown	—	—	$300,000
Minneapolis, Minn.	Feb. 26, 1919	Sparks from switch engine	—	—	$30,000

TABLE XXV — *Continued*

PLANT DUST EXPLOSIONS IN THE UNITED STATES AND CANADA (Continued).

Location.	Date.	Supposed cause.	Number killed.	Number injured.	Damage.
		ELEVATORS—(Continued).			
Portland Ore.	Mar. 24, 1919	Unknown	—	—	$3,000
Milwaukee, Wis.	May 20, 1919	Foreign material	3	4	$150,000
Dyersburg, Tenn	June 2, 1919	Hot bearing	—	—	Very limited
Port Colborne, Ont.	Aug. 9, 1919	Choke in elevator	10	10	$1,500,000
Kansas City, Mo	Sept. 13, 1919	Electric spark	14	10	$500,000
Memphis, Tenn.	Oct. 13, 1919	Unknown	—	1	$2,000
South Chicago, Ill.	Mar. 19, 1921	Fire in driers	6	Several	$3,000,000
Baltimore, Md.	July 5, 1921	Not determined	—	3	$3,000
Montreal Quebec	Oct. 27, 1921	Not determined	—	—	$11,000
		FEED AND CEREAL MILLS.			
Cedar Rapids, Iowa	Jan. 11, 1902	Sparks in dust collector	—	—	$1,800
Joliet, Ill.	Sept. 19, 1902	Spark in leg from metallic substance.	—	—	$1,500
DeLamere, N. D.	Mar. 21, 1903	Sparks in grinding machine.	—	—	$20,000
Cedar Rapids, Iowa	Mar. 5, 1905	Sparks in grinding machine.	1	3	$1,000,000
Boone, Iowa	May 17, 1906	Sparks in grinding machine.	—	—	$26,000
Shadyside, N. J.	May 22, 1906	Sparks by foreign material.	1	—	$75,000
Canal Fulton, Ohio	Dec. 21, 1907	Metallic substance in grinders.	—	—	$30,000
Peterborough, Ont., Canada.	June —, 1908	Metallic substance	—	—	Partial
Buffalo, N Y.	April 28, 1909	Unknown	—	—	$150,000
Buffalo, N.Y.	Jan. 4, 1910	Unknown	5	7	$118,000
Granite City, Ill.	Aug. 7, 1910	Foreign material in grinder.	2	7	$40,000
Batavia, N. Y.	Nov. 13, 1910	Metallic substance	—	—	Partial
Buffalo, N. Y.	June 24, 1913	Unknown	33	80	$465,000
Keokuk, Iowa	Sept. 11, 1913	Sparks in grinding machine.	—	—	$42,500
Buffalo, N. Y.	Sept. 13, 1913	Foreign material	1	7	$180,000
Fort Dodge, Iowa	Nov. 6, 1913	Sparks from grinding machine.	—	2	$1,200
Battle Creek, Mich.	Oct. 30, 1914	Foreign material	—	—	Partial
Toronto, Ont., Canada.	Dec. 13, 1915	Match	—	—	Partial
Davenport, Iowa	Jan. —, 1915	Attrition mills	—	—	Partial
Peterborough, Ont., Canada.	Dec. 11, 1916	Sparks in grinding	17	16	$2,000,000
South Bartonville, Ill.	Jan. 1, 1919	Electric spark	—	—	$750,000
Portland, Ore.	Mar. 24, 1919	Sparks in grinding machine.	—	—	$3,000
Buffalo, N. Y.	Mar. 26, 1919	Unknown	—	—	Small
Peterborough, Ont., Canada.	July 31, 1919	Sparks in grinding	—	—	Partial
Peterborough, Ont., Canada.	Aug. 18, 1919	Sparks in grinding	—	—	Partial
Buffalo, N. Y.	Sept. 12, 1919	Unknown	—	3	$20,000
Brandon, Man., Canada.	Oct. 21, 1920	Unknown	—	1	$10,000
Memphis, Tenn.	——	Unknown	—	—	$20,000
Joliet, Ill.	——	Metallic substance	—	—	$1,600
Buffalo, N. Y.	Nov. 22, 1921	Broken electric lamp bulb.	—	2	$4,000
		STARCH AND CORN PRODUCTS, PLANTS.			
New York, N. Y. (Confectionery plant).	Dec. 20, 1877	Breaking of lamp	—	—	$120,000
Grand Rapids, Mich. (Confectionery plant).	Jan. —, 1883	Open gas jet	—	—	Partial
Bradley, Ill.	Mar. 12, 1901	Unknown	—	—	$230,000
Waukegan, Ill.	Feb. 24, 1904	Unknown	1	—	$314,000
Oswego, N. Y.	July 1, 1907 / Sept. 28, 1907	Unknown	—	—	$15,000
Providence, R. I.	Feb. 12, 1908	Unknown	7	—	$35,000
Roby, Ind.	May 8, 1908	Unknown	—	—	$60,000
Roby, Ind.	Mar. 7, 1910	Flame from burning waste in drying tunnels.	4	10	$30,000
Lansdale, Pa. (Cassava starch dust).	April 16, 1911	Lantern	—	4	Partial
Chicago, Ill.	Nov. 18, 1910	Spark from nail	—	—	$2,000
Waukegan, Ill.	Nov. 25, 1912	Unknown	14	19	$100,000
Edgewater, N. J.	Sept. 22, 1914	Static electricity	2	3	Partial
Edgewater, N. J.	Dec. 21, 1915	Unknown	1	11	$25,000
New Orleans, La.	Dec. —, 1918	Static electricity	—	—	Very limited
Baltimore, Md. (Dextrine plant).	Jan. 22, 1919	Foreign material or excessive heat.	—	—	Partial
Argo, Ill.	Mar. 12, 1919	Broken electric light bulb in bin.	—	2	Partial
Cedar Rapids, Iowa	May 22, 1919	Spark from foreign material.	43	30	$3,000,000

TABLE XXV — *Continued*

PLANT DUST EXPLOSIONS IN THE UNITED STATES AND CANADA (Continued).

Location.	Date.	Supposed cause.	Number killed.	Number injured.	Damage.
RICE MILLS.					
New Orleans, La.	April 17, 1918	Sparks in attrition mill	—	—	$30,000
Beaumont, Tex.	July 25, 1916	Unknown	—	—	$300,000
BREWERIES AND MALT HOUSES.					
New York, N. Y.	July 4, 1880	Sparks from stones or metal in machine.	—	—	Partial
New York, N. Y.	July 30, 1881	Unknown	—	—	Partial
New York, N. Y.	May —, 1889	Spark from mill	—	—	Partial
Portsmouth, N. H.	Jan. 18, 1901	Unknown	—	—	$15,000
Boston, Mass.	Dec. 5, 1905	Foreign material	—	—	Partial
Springfield, Mass.	Sept. 13, 1907	Sparks from grinder	—	—	$1,600
Boston, Mass.	July 23, 1908	Foreign material	—	—	Slight
Boston, Mass.	May 31, 1911	Foreign material	—	—	Partial
Portsmouth, N. H.	Aug. 11, 1911	Unknown	—	—	$2,000
San Francisco, Cal.	Sept. 13, 1911	Foreign material	—	—	Partial
Chicago, Ill.	Oct. 7, 1916	Unknown	—	4	$25,000
Milwaukee, Wis.	Oct. 15, 1916	Unknown	—	—	$500,000
Buffalo, N. Y.	—— 1919	Unknown	—	—	Slight
SUGAR REFINERIES.					
Philadelphia, Pa.	Aug. 20, 1891	Open gas light	—	—	Partial
Franklin, La.	Oct. 7, 1910	Unknown	—	—	$300,000
Brooklyn, N. Y.	April 28, 1911	Spark from blower fan	—	—	Partial
White Castle, Ind.	Oct. 21, 1911	Unknown	—	—	$50,000
Philadelphia, Pa.	Feb. 27, 1914	Striking mill disks	—	—	Partial
New York, N. Y. (Confectionery plant).	Feb. —, 1914	Sparks from foreign material.	—	1	—
New York, N. Y. (Confectionery plant).	Nov. 8, 1916	Unknown	—	—	Slight
Brooklyn, N. Y.	June 13, 1917	Pulverizing machine	12	24	$1,000,000
Brooklyn, N. Y.	Oct. 1, 1919	Unknown	—	—	Slight
Brooklyn, N. Y.	Oct. 11, 17, 18, 1919	Foreign material in pulverizer.	—	—	Slight
Brooklyn, N. Y.	Jan. 23, 1920	Foreign material	—	—	Slight
Chicago, Ill.	June 16, 1920	Arc from electric switch	—	—	Slight
WOODWORKING PLANTS.					
Detroit, Mich. (Car works).	Nov. —, 1874	Dust ignited by flames from fire.	—	11	Partial
Appleton, Wis.	May —, 1880	Dust from rafters fell on live coals.	—	—	Partial
Columbus, Ohio (Buggy works).	—— 1886	Furnace ignited dust	—	1	Partial
Oshkosh, Wis. (Lumber mill).	Aug. 28, 1895	Sparks from fly wheel	—	—	Complete
New York, N. Y.	Jan. 31, 1901	Unknown	—	—	$1,000,000
Buffalo, N. Y. (Door and box factory).	April 6, 1901	Oily waste	—	—	$4,000
Wausau, Wis.	April 18, 1901	Fire blown from an explosion of dust in boiler furnace to shavings vault.	—	—	Slight
Boston, Mass.	Nov. 27, 1905	Sparks from shovel	—	1	Slight
Fitchburg, Mass.	Feb. 7, 1906	Dust blown into furnace	—	—	Partial
Barber, Cal. (Match factory).	Aug. 6, 1910	Dust blown into furnace	2	Several	Complete
Philadelphia, Pa.	Feb. 5, 1913	Metallic sparks	1	1	Slight
Nashua, N. H.	June 11, 1913	Unknown	—	—	Partial
New Albany, Ind.	Aug. 1, 1913	Water thrown with force into sawdust during fire.	—	—	Partial
Montreal, Ont., Canada.	Nov. 7, 1913	Unknown	—	—	Partial
St. Louis, Mo. (Chair factory).	Nov. 25, 1913	Open lantern	—	—	Partial
Philadelphia, Pa. (Box fact.)	—— 1913	Bolt in cutting machine	1	6	Partial
Boston, Mass.	Jan. 3, 1914	Unknown	—	—	Slight
Brooklyn, N. Y. (Cooperage plant).	June —, 1914	Dust in furnace	2	—	Partial
St. Joseph, Mich. (Door factory).	Dec. 21, 1914	Unknown	—	—	Slight
Camden, N. J. (Talking machine factory).	Oct. 27, 1914	Fire from back-draft in dust pipe. (Wood dust).	—	—	$6,500

TABLE XXV — *Continued*

PLANT DUST EXPLOSIONS IN THE UNITED STATES AND CANADA (Continued).

Location.	Date.	Supposed cause.	Number killed.	Number injured.	Damage.
		WOODWORKING PLANT—(Continued)			
Portland, Maine	July —, 1915	Unknown	1	—	Partial
Tacoma, Wash. (Door factory).	July 17, 1917	Fire in cyclone	—	—	$120,000
Boston, Mass	Feb. 7, 1918	Spark from machine	—	—	Slight
New York, N. Y.	Sept. 25, 1919	Spark in machine	—	—	$160
Three Rivers, Mich. (Wood handle factory).	Aug. 17, 1920	Fire from heading machine.	—	—	$15,000
Chicago, Ill.	Nov. 8, 1920	Carbonized sawdust	—	Several	Slight
Buffalo, N. Y.	Mar. 3, 1921	Unknown	—	—	$75,000
		MISCELLANEOUS.			
New Kensington, Pa. (Aluminum plant).	Nov. 5, 1917	Spark from sledge hammer.	7	15	$175,000
Manitowoc, Wis. (Aluminum Mfg. plant).	Feb. 26, 1920	Spark from wire in exhaust fan.	6	4	Slight
Leominster, Mass. (Celluloid plant).	Sept. 3, 1913	Spark from machine	—	—	Slight
Boston, Mass (Chocolate factory).	Mar. 30, 1914	Foreign material in blower fan.	—	—	Partial
Burlington, Vt. (Chocolate factory).	April 25, 1918	Spark in fan	3	1	$750,000
Pittsburgh, Pa. (Cork factory).	Dec. 11, 1903	Unknown	—	—	Partial
Philadelphia, Pa. (Oil cloth factory—cork dust).	Aug. 13, 1913	Dust (cork) on pipes in drier.	—	—	$6,000
Philadelphia, Pa. (Oil cloth factory — cork dust).	Mar. 27, 1914	Foreign material in grinders.	—	—	—
Baltimore, Md. (Cork factory).	June 29, 1917	Overheated cork in attrition mill.	—	—	$120
Nicetown, Pa. (Oil cloth factory — cork dust).	Feb. 27, 1918	Stream turned on pile of dust.	—	7	—
Philadelphia, Pa. (Cork factory).	Feb. 1, 1919	Friction from broken belt...	—	—	Small
Philadelphia, Pa. (Cotton mill).	Aug. 19, 1907	Unknown	—	—	Partial
Denver, Colo. (Cotton mill)	Jan. 10, 1910	Unknown	—	—	Partial
Woonsocket, R. I. (Cotton mill).	Oct. 24, 1913	Unknown	2	—	Partial
Nashua, N.H. (Cotton mill)	Jan. 19, 1914	Unknown	—	—	Partial
Cleveland, Ohio (Cotton and woolen works).	Oct. 7, 1916	Sparks from fan	—	—	Partial
Portsmouth, Va. (Fertilizer plant).	Jan. 28, 1908	Nail in pulverizing mill	—	—	$10,000
St. Joseph, Mo. (Fertilizer plant).	Dec. 27, 1908	Unknown	—	—	Partial
Philadelphia, Pa. (Fertilizer plant).	June 21, 1909	Unknown	—	—	$8,000
Philadelphia, Pa. (Fertilizer plant).	May 3, 1910	Unknown	—	—	Partial
Fort Worth, Tex. (Fertilizer plant).	Aug. 1, 1912	Unknown	—	—	Partial
Chicago, Ill. (Fertilizer plant)	Jan. 9, 1915	Unknown	—	—	Partial
Chicago, Ill. (Fertilizer plant)	Jan. 4, 1916	Sparks struck by elevator bucket.	—	—	Small
Buffalo, N.Y. (Fertilizer plt.)	Mar. 12, 1916	Unknown	7	—	Partial
Chicago, Ill. (Fertilizer plant)	May 24, 1916	Unknown	—	—	—
Chicago, Ill. (Fertilizer plant)	July 14, 1916	Unknown	—	—	—
Chicago, Ill. (Fertilizer plant)	Mar. 10, 1919	Unknown	—	—	Slight
Anoka, Minn. (Powdered milk factory).	July 10, 1918	Sparks in drying chamber.	—	—	$30,000
Pejepscot, Maine (Paper plant).	Feb. 3, 1914	Sparks from saw	—	—	$6,700
Bristol, N. H. (Paper plant).	Feb. 7, 1914	Static electricity	—	—	$4,700
Bridgeport, Conn. (Phonograph factory).	Mar. 27, 1917 Mar. 6, 1918	Foreign material	—	1	$800
West Orange, N. J. (Phonograph factory).	May 11, 1917	Metal in grinders	—	—	$35,000
Danversport, Mass. (Rubber reclaiming factory).	Jan. 6, 1914	Foreign material in grinders.	—	—	Partial
Muskegon, Mich. (Rubber recovery plant).	Aug. 18, 1920	Not determined	8	1	$25,000

TABLE XXV — *Continued*

PLANT DUST EXPLOSIONS IN THE UNITED STATES AND CANADA (Continued).

Location.	Date.	Supposed cause.	Number killed.	Number injured.	Damage.
		MISCELLANEOUS—(Continued.)			
Cleveland, Ohio (Shoddy mill).	Feb. 27, 1910	Spark struck by workman's hoe.	—	3	Partial
Cleveland, Ohio (Shoddy mill).	Mar. 18, 1910	Unknown	—	—	$100
Providence, R. I. (Soapine works).	Aug. 4, 1890	Open gas burner	2	9	Partial
Newark, N. J. (Spice and shellac factory).	Jan. 29, 1915	Foreign material	—	—	Partial
Cincinnati, Ohio (Tea and spice mill).	Jan. 17, 1920	Flames of fire ignited spice dust.	4	13	$150,000
Toronto, Ont., Canada (Sulphur dust).	April —, 1911	Static electricity	—	—	$500
Toledo, Ohio (Sulphur dust)	Dec. 16, 1921	Static electricity	—	—	Slight
Louisville, Ky. (Sulphur dust)	Mar. 12, 1922	Sparks	—	—	Partial
New York, N. Y. (Sulphur dust).	Nov. 25, 1912	Elevator buckets striking sparks.	—	15	Partial
Boston, Mass. (Rubber factory, sulphur dust).	Feb. 6, 1913	Static electricity	—	—	$100
Hartford, Conn. (Rubber works, sulphur dust).	Feb. 23, 1914	Static electricity	—	—	Slight
Hudson, Mass. (Tannery)	April 10, 1913	Unknown	—	—	$1,000
——, Michigan (Tannery)	Aug. 29, 1916	Friction in grinders	—	—	$800,000
New York, N. Y. (Fur cleaning works, wood and flour dusts).	July 2, 1889	Candle	—	4	$1,300
		PLANT DUST EXPLOSIONS IN EUROPE UP TO 1921.			
Glasgow, Scotland (Flour mill).	July 9, 1872	Sparks from mill stones	18	16	$350,000
Budapest, Hungary (Flour mill).	—— 1878	Open lantern	—	—	Partial
Sorgues, France (Garancine factory).	Nov. 13, 1878	Lantern	6	—	Partial
Macclesfield, England (Corn mill).	Sept. 14, 1881	Mill stones running empty	—	—	Partial
Rochdale, England (Flour mill).	Feb. —, 1882	Mill stones striking fire	—	—	$130,000
Corbeil, France (Cereal mill).	—— 1892	Lantern	4	—	Partial
Angers, France (Confectionery works).	July 6, 1904	Starch falling on heating pipes.	1	3	Partial
Paris, France (Sugar refinery).	May 22, 1908	Electric sparks	3	49	Partial
Manchester, England (Dextrine works).	Mar. 21, 1911	Fire in fan casing	3	5	Partial
Glasgow, Scotland (Feed mill).	Nov. 10, 1911	Open flame	5	8	Partial
Liverpool, England (Linseed meal mill).	Nov. 24, 1911	Unknown	39	101	Partial
Aberdeen, Scotland (Feed mill).	Dec. —, 1911	Foreign material	—	1	Partial
Manchester, England (Dextrine works).	Mar. 11, 1913	Unknown	3	5	Partial
Tourcoing, France (Paper mill).	May 31, 1913	Lantern	2	—	Partial
Ossett, York, England (Rag carbonizing plant).	June 2, 1913	Friction of match in pocket.	—	3	Partial
Selford, England (Brewery)	June 19, 1913	Open gas flame	—	1	Partial
Lancaster, England (Linoleum works).	June 24, 1913	Sparks in cork grinding machine.	—	3	Partial
Manchester, England (Oil cake factory).	June 24, 1913	Hot flue dust	—	2	Partial
Liverpool, England (Oil cake mill).	Sept. 5, 1913	Foreign material in elevator buckets.	—	2	Partial
Mitcheldean, England (Cement works).	Sept. 8, 1913	Sparks from rotary kiln (coal dust).	—	1	Partial
Wandsworth, England (Graphophone record factory)	Nov. 21, 1913	Foreign material (Copal gum)	—	4	Partial
Rhenish Palatinate, Germany (Sugar works).	Feb. —, 1916 May —, 1917	Unknown	7	Several	Partial
Kuopio, Finland (Grain elevator).	July 23, 1919	Sparks from friction of belt.	—	—	Complete
Czegled, H'ng'ry (Flour mill)	Recently	Breaking of electric bulb	—	—	—

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